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Earth as Interface: Exploring chemical senses with Multisensory HCI Design for Environmental Health Communication

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Dedication

To my parents Carlos and Graciete.
To my partner in life and love Nuno Lima.

PhD Program

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Abstract

As environmental problems intensify, the chemical senses -that is smell and taste, are the most relevant senses to evidence them. As such, environmental exposure vectors that can reach human beings comprise air, food, soil and water [1]. Within this context, understanding the link between environmental exposures and health [2] is crucial to make informed choices, protect the environment and adapt to new environmental conditions [3]. Smell and taste lead therefore to multi-sensorial experiences which convey multi-layered information about local and global events[4]. However, these senses are usually absent when those problems are represented in digital systems.

The multisensory HCI design framework investigates chemical sense inclusion with digital systems [5]. Ongoing efforts tackle digitalization of smell and taste for digital delivery, transmission or substitution [6]. Despite experiments proved technological feasibility, its dissemination depends on relevant application development [7].

This thesis aims to fill those gaps by demonstrating how chemical senses provide the means to link environment and health based on scientific and geolocation narratives [8], [9], [10]. We present a Multisensory HCI design process which accomplished symbolic displaying smell and taste and led us to a new multi-sensorial interaction system presented herein.

We describe the conceptualization, design and evaluation of *Earthsensum*, an exploratory case study project. *Earthsensum* offered to 16 participants in the study, environmental smell and taste experiences about real geolocations to participants of the study. These experiences were represented digitally using mobile virtual reality (MVR) and mobile augmented reality (MAR). Its technologies bridge the real and digital Worlds through digital representations where we can reproduce the multi-sensorial experiences.

Our study findings showed that the purposed interaction system is intuitive and can lead not only to a better understanding of smell and taste perception as also of environmental problems. Participants comprehension about the link between environmental exposures and health was successful and they would recommend this system as education tools. Our conceptual design approach was validated and further developments were encouraged.

In this thesis, we demonstrate how to apply Multisensory HCI methodology to design with chemical senses. We conclude that the presented symbolic representation model of smell and taste allows communicating these experiences on digital platforms. Due to its context-dependency, MVR and MAR platforms are adequate technologies to be applied for this purpose. Future developments intend to explore further the conceptual approach. These developments are centred on the use of the system to induce hopefully behaviour change. This thesis opens up new application possibilities of digital chemical sense communication, Multisensory HCI Design and environmental health communication.

Keywords: Environmental Health Communication, Multisensory HCI Design, Sustainable HCI, Chemical Senses, Smell, Taste, Symbolic Representation System, Mobile Virtual Reality, Mobile Augmented Reality, Human Chemical Communication.

Resumo

À medida que os problemas ambientais se intensificam, os sentidos químicos - isto é, o cheiro e sabor, são os sentidos mais relevantes para evidenciá-los. Como tais, os vetores de exposição ambiental que podem atingir os seres humanos compreendem o ar, alimentos, solo e água [1]. Neste contexto, compreender a ligação entre as exposições ambientais e a saúde [2] é crucial para exercer escolhas informadas, proteger o meio ambiente e adaptar a novas condições ambientais [3]. O cheiro e o sabor conduzem assim a experiências multissensoriais que transmitem informações de múltiplas camadas sobre eventos locais e globais [4]. No entanto, esses sentidos geralmente estão ausentes quando esses problemas são representados em sistemas digitais.

A disciplina do design de Interação Humano- Computador (HCI) multissensorial investiga a inclusão dos sentidos químicos em sistemas digitais [9]. O seu foco atual reside na digitalização de cheiros e sabores para o envio, transmissão ou substituição de sentidos [10]. Apesar das experimentações comprovarem a viabilidade tecnológica, a sua disseminação está dependente do desenvolvimento de aplicações relevantes [11].

Esta tese pretende preencher estas lacunas ao demonstrar como os sentidos químicos explicitam a interconexão entre o meio ambiente e a saúde, recorrendo a narrativas científicas e contextualizadas geograficamente [12], [13], [14]. Apresentamos uma metodologia de design HCI multissensorial que concretizou um sistema de representação simbólica de cheiro e sabor e nos conduziu a um novo sistema de interação multissensorial, que aqui apresentamos.

Descrevemos o nosso estudo exploratório *Earthsensum,* que integra a conceptualização, design e avaliação. *Earthsensum* ofereceu a 16 participantes do estudo experiências ambientais de cheiro e sabor relacionadas com localizações geográficas reais. Essas experiências foram representadas digitalmente através de realidade virtual (VR) e realidade aumentada (AR). Estas tecnologias conectam o mundo real e digital através de representações digitais onde podemos reproduzir as experiências multissensoriais.

Os resultados do nosso estudo provaram que o sistema interativo proposto é intuitivo e pode levar não apenas a uma melhor compreensão da perceção do cheiro e sabor, como também dos problemas ambientais. O entendimento sobre a interdependência entre exposições ambientais e saúde teve êxito e os participantes recomendariam este sistema como ferramenta para a educação. A nossa abordagem conceptual foi positivamente validada e novos desenvolvimentos foram incentivados.

Nesta tese, demonstramos como aplicar metodologias de design HCI multissensorial para projetar com os sentidos químicos. Comprovamos que o modelo apresentado de representação simbólica do cheiro e do sabor permite comunicar essas experiências em plataformas digitais. Por serem dependentes do contexto, as plataformas de aplicações em VR e AR são tecnologias adequadas para este fim.

Desenvolvimentos futuros pretendem aprofundar a nossa abordagem conceptual. Em particular, aspiramos desenvolver a aplicação do sistema para promover mudanças de comportamento. Esta tese propõe novas possibilidades de aplicação da comunicação dos sentidos químicos em plataformas digitais, de design multissensorial HCI e de comunicação de saúde ambiental.

Palavras-chave: Comunicação de saúde ambiental; design multissensorial HCI, HCI sustentável, sentidos químicos; cheiro; gosto; sistema de representação simbólica; realidade virtual; realidade aumentada, comunicação química humana.

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Abbreviations

AR	Augmented Reality
APP	Application
HCI	Human-Computer Interaction
HMD	Head Mount Display
MAR	Mobile Augmented Reality
MVR	Mobile Virtual Reality
SDG	Sustainable Development Goals
UI	User Interface
UX	User Experience
VR	Virtual Reality

Part I - Presentation

"The negative environmental impact of human activity (…) were not necessary. They were all avoidable. Increasingly, pollution is no longer seen as a sign of progress, but as a sign of inefficiency and carelessness [12, p. 121]."
Donella Meadows, 2001

1. Background

Based on the recognition that human health and well-being are intimately linked to the environment, raising environmental literacy within communities and citizens is crucial to foster pro-environmental behaviour [2]. By definition, environmental health is the science and practice of preventing human injury and illness, promoting well-being by identifying and controlling environmental sources and hazards agents [13]. These comprise all the physical, chemical, and biological factors external to a person, and all the related factors impacting behaviour [14]. Present environmental problems, such as global warming, reflect human activities impact since the Industrial Revolution [15]. Recent report trends are pointing towards progressive global socio-economic pressure [16] and population health risks [17]–[19]. These trends were announced already by pioneering studies of 20th century [20] alerting that the quest of unlimited economic growth would lead to system collapse, due to the earth's limited resources. Meanwhile, the 21st-century evolving environmental hazards have led to new policy efforts [21], such as transition to low-carbon economy and sustainable food systems [22]. These lines of actions fall within the scope of the latest environmental health strategies recommended by the World Health Organization (WHO) [23]. They include the commitment to sustainable patterns of consumption and production, as well as it tackles the misuse of natural resources and the large-scale generation of waste. WHO argues that if these strategies could be implemented on time, more economic and health risks could be reduced. Accordingly, we assume, that the more people know how to interpret their environment, the more they will act in accordance with these transition strategies.

1.1. Motivation

Motivation for our research derives from a personal conviction that design practice provides the resources to help solve human problems, in this case, the environmental-human/tech relationship amid climate change. Studies which endorse the climate change and environmental health field are considered strategic, as they emphasize human and eco-system well-being at risk in a rising global warming scenario [17]. Its relevancy is related to United Nations Sustainable Development Goals (SDG) [24] such as SDG3 - ensure healthy lives and promote well-being for all at all ages and SD13 - take urgent action to combat climate change and its impacts, which implies amongst others to SDG12 - ensure sustainable consumption and production patterns. Likewise, studies which explore the chemical senses inclusion in Human-Computer Interaction (HCI) are also considered strategic, as they envision new interaction forms against prevailing vision, hearing, and touch interaction senses in technology [25].

Emergent field of Multisensory HCI has focused on technology-oriented research laying on cross-modal correspondence findings [26] to explore systematization and application possibilities. Despite of technological feasibility demos, its expansion is depending on how to design meaningful experiences within Multisensory HCI framework. Concerning current HCI research agenda, change of perspective is pointing towards human and social values in terms of individual and societal needs of human life, such as sustainability [27]–[29]. In this context, this research work is strategic as it combines human - societal needs and technology, intending to provide tools for citizens to engage with environmental health information through chemical sense experiences for behaviour change.

1.2. Problem definition

This thesis states that smell and taste lead to multi-sensorial experiences which convey multi-layered information about environmental events [4]. However, to the best of our knowledge, these senses are usually absent when those problems are represented in digital systems. Geographic Information Systems (GIS) enabled multidimensional environmental systems [30] to evolve since the event of the World Wide Web (WWW)[31]. As broadband and technological advances provided web mapping and location-based services, which enabled the public to interact with geographic data. Platforms and services have evolved to collect, monitor, predict and interpret environmental data through governmental and public sources [32], [33]. Nevertheless, the chemical sense dimension is absent from these representations. Despite reporting tools of environmental smell incidents are improving [34], [35] there is no correlation with taste.

The goal of this work is to investigate if environmental health communication design strategies benefit from multisensory interaction systems which include smell and taste experiences. Our approach relies on the fact that human organism can be reached by environmental exposure vectors through air, food, soil and water conditions [1]. This implies that through breathing and ingestion, environmental pollutants enter imperceptibly into the human body triggering health issues [1], [3], [36]. To evidence these events, the chemical senses are the most relevant. However, there is a lack of design solutions which embraces the inherent representative dimensions [8] of this correlation. This thesis reveals how Multisensory HCI design practice provides the baselines to explore solutions for this challenge [8].

Concluding, the presented motivations of this introduction, guides this thesis to explore the following main goals:

To give people the tools for them
(1) to explore their chemical senses and communicate them;
(2) to make the connection between smell and taste with objective and subjective environmental information; in order
(3) to leverage their knowledge about environmental health and make informed choices for sustainability and transition.

1.3. Research questions

In response to the goals presented, our research specially asks:

R 1. How can the chemical senses be included in digital media design?

R 2. How can chemical sense communicate environmental health on digital platforms?

To answer these central questions, we address three secondary questions:

- **R 2.1. How can the chemical sense be applied to inform such a system?**

- **R 2.2. How is the design strategy of such Multisensory HCI Experience?**

- **R 2.3. What is the Impact of this Multisensory HCI Experience on Users?**

This research explores the properties of smell and taste as communication systems on digital platforms. We seek ways of revealing environmental health information through human sensorial perception, by applying the multidisciplinary approach of digital media design.

1.4. Methodology

In pursuance of answer our research questions we followed research through design methodology in HCI [37]. This approach builds on "an active process of ideating, iterating and critiquing potential solutions" [1, p. 497] to produce knowledge about an identified problem. The design stages of this process entail (1) background research, (2) prototype creation, (3) prototype and process analyses, which leads to (4) new or modified theory development.

Broadly, our study is structured as proof-of-concept. It is composed by two main parts: the concept experience and the concept evaluation. The concept experience englobes the chemical sense experience and the digital media experience. The concept evaluation analyses its underlying assumptions.

Overall, our exploratory study required a mixed method approach [38]. Our experiment follows a within-subject design that we conducted with 16 participants. We thereby collected and analysed qualitative and quantitative data that we gathered trough online questionnaires, semi-structured interviews and observation notes. Regarding open-ended questions, we analysed the data through inductive thematic analysis. This approach organizes the data without imposing a pre-existing coding frame[39]. This method implies to read the written comments repeatedly to find data pattern and find relevant information in relation to the theme.

Herein we present each design stage and its inherent methodologies:

1.4.1. Background research

Starting our research study, we examined previous studies related to chemical sense application in Multisensory HCI Design to answer research question 1. We also reviewed cross-modal correspondence findings of smell and taste experiences, which could inform our concept [40], [41] to answer research question 2. In addition, we researched about environmental health and climate change for problem framing.

The search of the literature considered platforms such as Web of Knowledge and ACM Digital Library. A combination of the following terms was used: "Multisensory HCI", "Chemical Senses", "Crossmodal Correspondences", "Sustainable HCI", "Environmental Health Communication", "Olfactory Design", "Food Interaction", Environmental Smell", "Environmental Taste", "Virtual Reality" and "Augmented Reality". A valuable additional strategy included investigating the reference list of the articles selected for review.

The background research framed our study theoretically and conceptually. Its key findings provided information and insights to inform the next design stage.

1.4.2. Prototype (creation and process analyses)

Based on the findings of previous phase, we conceptualized a design rationale and formulated design hypothesis [42], which our Multisensory HCI Design process had to address. Based on synesthetic design methodology [43], we conceptualize the design project *Earthsensum* as a proof-of-concept, that had to prove its:

- Feasibility
- Relevancy
- Acceptance

The design process comprised two main design phases: the chemical sense experience and the digital media experience. First, the environmental smell and taste experience without contextualization. Second, the contextualization providing experience with mobile virtual reality (MVR) and mobile augmented reality (MAR) prototypes. These follow synesthetic design methodology requisites of aligning cross-sensory analogies with the design mission intent. Therefore, this design process unfolds along two main building layers - first, a cross-sensory analogy and symbolic construction layer, followed by a meaning and communication construction layer.

1.4.2.1. The cross-sensory analogy and symbolic construction layer

This design stage relies on cross-modal correspondences research [40], [41] as they lay the foundations for multisensory design [43]. As our experiment refers to real-life situations in which smell or taste experiences happen, we simulated these by providing taste and smell samples. These samples were selected by its objective and subjective connotations organized by categories. for content development in the following prototyping stage. For each taste or smell experience, we collected association data along semantic, haptic, graphic and hedonic dimensions. The combination of these variables allows to a communicate a perception or emotion, as also lay the foundations to conceptualize a symbolic representation system for digital platforms. To accomplish the chemical sense experience study, we adapted a mixed method approach. We adopted observation, questionnaires and semi-structured interviews to analyse people communicate skills of environmental related smell and taste, without contextual clues. Initially we considered to gather olfactory bio-feedback. We conducted an informal pre-study experiment with one volunteer and three familiar smell samples, to test the BITalino (r)evolution Plugged Kit BT equipment [44]. It provides sensors and actuators to measure to measure for example, electrodermal activity. The test allowed us to conclude, that this approach required expertise resources that was out of the scope of our research (Appendix C - Figure 43, Figure 44).

1.4.2.2. The meaning and communication construction layer

After the chemical sense experience, the experiment progresses towards its functional proposal. This is worked out by the meaning and communication layer, whose purpose is to deliver a message or service through a digital platform, to a specific audience. To this end, cognitive association and contextual factors have to be congruent with the design intent. For this design stage, we applied User Experience (UX) methodology for developing our digital product concepts and prototypes. In its core, the design process builds up incrementally: strategy, scope, structure, skeleton and surface [45]. Starting from abstract towards a "material" expression of the digital application, the strategy level involves application objectives and user needs; the scope level requires functional specifications and content requirements; the structure level refers to Interaction design and information architecture; the skeleton level entails interface and information design; concluding with the surface level corresponding visual design. Prototype design followed this general methodology, to meet the research goals. *Earthsensum* design hypothesis embraced virtual reality and augmented reality technology, we developed accordantly all documentation and design material for its implementation [46]. User Experience Evaluation methods informed the prototype evaluation. Adopting goal-oriented task action, we applied first click testing [47] to the MAR app, and walkthrough method [48] to the MVR app evaluation. We gathered quantitative and qualitative data through observation, questionnaires (applying the Likert scale,) and semi-structed interviews. This procedure allows to inform the design process as in case to detect and solving design problems before evolving into more advanced prototype versions. In this research work, it discloses also proof-of-concept assumptions for each design hypothesis.

1.4.3. New or modified theory development/ critiquing

These methodological steps [49], conducted as to the last design stage of this process. It corresponds to the concept evaluation, which validates positively or not, our proof-of-concept validation. To this end we conducted semi-structured interviews with open ended questions. This stage allows also to use what was observed during the experiment and exploit the potential of the data for developing theory, as defined by research through design methodology [50]. Regarding interaction design, Zimmerman et al.[37] has suggested four criteria to evaluate the contribution of a research: Process (specific methods applied); Invention (contribution to the current state of knowledge); Relevance (leading or supporting a preferred state of the world); and Extensibility (documentation as a basis for new research). In this line, "this knowledge and this understanding results from the making of an artefact that, (…) is embodied in the artefact created or designed" [50, p. 10].

1.5. Research Contributions

The work developed within this thesis. contributes towards:

1.5.1. Smell and taste symbolic representation system for digital platforms

The research offers insight on how to build a symbolic representation system of smell and taste perceptions in augmented and virtual reality environments. This research shows that non-verbal communication is suitable for digital implementation. As these are related to a geographical event in time and space, further representation forms of mapping practices could be developed. This opens new possibilities to design for environmental communication relationships with respect to integrating equally the human subjective and objective experience

1.5.2. Environmental health communication strategies with the chemical senses

This research contributes to the discussion of chemical sense inclusion in environmental health communication Not only participants praised the opportunity of having acknowledged how their sense of smell or taste informed their every-day experience, as also they appreciated to discover how the chemical senses are blended with environmental information. This research demonstrates that digital media experiences increased both chemical sense and environmental awareness. In these terms, stimulates new perspectives on how to design persuasive environmental communication strategies for the non-scientific public. Furthermore, this research proves that the conceptual baseline of linking chemical sense and environmental health benefits environmental education due to its high evaluation as an innovative approach.

1.5.3. Multisensory HCI design framework.

The design practices created in this research uncovered new application opportunities for HCI and environmental communication design. Furthermore, it exemplifies a meaningful application of multisensory HCI design, as Obrist et al. [5] called for in the HCI community.

1.6. Thesis Publications

- Neves P., Câmara A. (2020) Multisensory HCI Design with Smell and Taste for Environmental Health Communication. In: Stephanidis C., Marcus A., Rosenzweig E., Rau PL.P., Moallem A., Rauterberg M. (eds) HCI International 2020 - Late Breaking Papers: User Experience Design and Case Studies. HCII 2020. Lecture Notes in Computer Science, vol 12423. Springer, Cham. https://doi.org/10.1007/978-3-030-60114-0_31

  The paper presents our Multisensory HCI design framework presented in Part Three.

- We have submitted the manuscript "We are not Robots: environmental communication for multi-sensorial humans" to international academic publisher "The Design Journal" (Taylor & Francis Group).

  This article presents the concept of the symbolic representation systems based on our crossmodal association results. It also situates our research conceptually in the field of environmental health communication design. The article corresponds to Part Two.

1.7. Structure of the document

Part One presents background thoughts that motivated this thesis. In addition, it also defines the problem to solve, research questions and methodology. The section concludes with the thesis contributions do knowledge and publications.

Part Two deals with the main RQ1: "How can the chemical senses be included in digital media?" and RQ2: How can chemical sense communicate environmental health on digital platforms?" The section presents the state-of-the art of (1) environmental communication and technology and (2) the chemical sense inclusion in environmental health communication.

Part Three deals with the three secondary questions: R 2.1. "How can the chemical sense be applied to inform such a system?"; R 2.2. "How is the design strategy of such Multisensory HCI Experience?" and R 2.3. "What is the Impact of this Multisensory HCI Experience on Users? The section presents the concept experience and the concept evaluation of *Earthsensum*, our exploratory design project study. It includes the Multisensory HCI design process of conceptualizing, designing and implementing mobile virtual reality (MVR) and mobile augmented reality (MAR) prototypes experiences with the chemical senses. In the end, evaluation results are presented, regarding the chemical sense, the digital media, and the conceptual experience.

Finally, conclusions and further work directives are discussed.

Part II - State-of-the-Art

“In contrast to the notion of objective function, Nature optimises for a multiplicity of simultaneous functions across scales: structural load, environmental performance, spatial constraints and more. (...) The intimate relationship between design and biology proposes a shift from consuming Nature as a geological resource to editing it as a biological one. (...) It requires a change in the way we see Mother Nature, from a boundless nourishing entity to one that begs nourishment by design.”[51, p. 300]
Neri Oxman, 2018

2. Introduction

In this section we investigate the main two research questions: **RQ 1:” How can the chemical senses be included in digital media design?”** and **RQ 2: “How can the chemical senses communicate environmental heath on digital platforms?”**

Environmental events may be represented by their physical, chemical, biological, social, and economic impacts. These are represented by qualitative and quantitative variables. Nevertheless, the chemical senses are underrepresented in these descriptions. Environmental communication has been adequate in solving the multi-dimensional nature by using added-on artificial sensors and indicators that compress vectors into scalars [52]. These mathematical readings do not equate the human experience, as the subjective emotional dimension is excluded from this equation. The chemical senses are indeed harder to account for as its detection and interpretation may vary from person to person. So far, what we have been accomplishing is to communicate environmental impacts for robots performing electronic sensor fusion [53], formatted to be read by humans. However, human nature is multi-sensorial. We are not robots.

Within this context, we state that technology and digital platforms must enable humans to establish a close communication relationship with the environment, to decode its underlying significances. Along this line, smell and taste experiences are direct interfaces of the environment as through breathing and ingestion the human body fuses environmental information in its organism. As these processes are nearly imperceptible, subjects are not aware of interacting with them. To the best of our knowledge, environmental communication design solutions have not addressed this challenge.

2.1. Environmental Communication and Technology

Communication shapes our perception of environmental issues, and in the way, we interact with our human fellows and with our environment. Pezzullo and Cox [54] have emphasized on how environmental communication is not a stoic transmission of information in terms of the Shannon-Weaver model [55] but is a form of symbolic action. Environmental communication is defined as "the pragmatic and the constitutive vehicle for our understanding of the environment as well our relationships to the natural world; it is the symbolic medium that we use in constructing environmental problems and negotiating society's different responses to them" [54, p. 20]. The authors emphasize how environmental communication enclosures connecting pragmatic and constitutive functions, and thereby acts on our awareness. The pragmatic function solves environmental problems such as education, mobilization, and persuasion. The constitutive function helps to build representations of nature and environmental problems themselves as subjects for our comprehension. These symbolic representations are achieved by (i) shaping our perception about the environment through symbols, language, imagery, or narratives and by (ii) helping to define certain subjects as problems through value association such as e.g. health, sustainability and economy. The environmental communication process concludes with the validation of these representations of the constitutive function by including the pragmatic function. Consequently, as the public is informed, educated or motivated to act on problems and values, new relationship possibilities with the environment are mediated.

Technology mediate these emergent formulations. Philosopher Peter-Paul Verbeek [56] sustains that through human interaction with technological artefacts, technology co-shape or co-constitute new practices and experiences. In these terms, technology definition is not mere functional or instrumental objects opposed to human subjects, as also is not mere extensions of human beings. Technology is predominantly a way of revealing, in the sense that knowledge provides an opening up of the reality that emerges out of concealment. According to philosopher Martin Heidegger [57], technology is an evolving vehicle reflecting on how we relate to the world which implies knowledge, craftsmanship and art. Consequently, besides being a system, it promotes and reveals new ways of relating to the world, environment and society, according to aesthetic and ethical codes.

In this context, we envision technology and digital platforms as complementary facilitators to accomplish a more refined and informed environment-human relationship. By doing so, positive sustainability strategies may be triggered and sustained. Following, we describe environmental communication as relationships of (1) "environment-human"; (2) "environment-machine-human" and (3) "environment-tech/human" (Figure 1) and reflect on design implications.

Figure 1 - Communication relationships: environment-human (left); environment-machine- human (middle); environment-human/tech (right).

2.1.1. The "environment- human" communication relationship

The "environment-human" communication relationship refers to the spontaneous human response to environment sensory input. As humans are multimodal emotional beings, these responses are shaped by the context and feelings, as also on prior experiences and knowledge transfer. In this sense, it integrates multisensorial, perception and cognition systems.

2.1.1.1. Human Sensory System.

The basic functioning of human sensory structures depends on stimuli, transduction and interpretation [58]. The sense organs comprise the eyes, ears, tongue, nose and skin. In this line, sensory stimuli received by the sense organs, respond to distinct receptors. These sensory pathways connect with nerve cells that carry the nerve impulses and transmit this input to the central nervous system. Accordingly, there are photoreceptors for light, mechanoreceptors for distortion or bending, thermoreceptors for heat, chemoreceptors for smell, and nociceptors for painful stimuli. Beyond the sense of vision, audition, touch, taste and smell, the human sensory system also integrates the sense of motion and the sense of balance. Receptors present in the muscles, tendons, and joints relate to proprioceptive and kinesthetic information. Receptors located in the inner ear is the vestibular sense which contributes to balance and body posture. All this neurochemical information ends up in specific receiving areas of the cerebral cortex following its stimuli source and function. The brain processes constantly and simultaneously various types of sensory inputs, to interpret the world in a meaningful manner. Neuroscience studies refer to this occurrence as multisensory integration processes [59]. They involve integrating incoming sensory inputs from various sensory modalities, in order to blend them as perceptual objects and thereby creating behavioural responses to be generated. Hence, the survival of an organism depends on appropriate responses to multisensory stimuli of its environment, based on perception.

2.1.1.2. Human Sensory Perception.

Psychologist James J. Gibson [60], [61] refers to the senses as perceptual systems, which determines our mental models and behaviour. Perceptual systems are described as the permanent relationship of living organisms and their environment composed of the medium, substances and surfaces. In this context, the medium is formed by air, gas and liquid, through which we move. These allow the transmission of light, vibrations, and chemical diffusions so we can see, hear and smell. Substances are more rigid components such as rock, soil, sand, wood and metal as well as plant and animal tissue. Finally, surfaces are the elements that separate the medium from the substances. As they reflect and absorb light or display olfactive and haptic attributes, they provide clues about the environment. These include colour, smell, texture, and temperature, among other properties.

In Gibson's vision, the environment decides perception and therefore meaning is in what the environment "affords" the observer. Perceptual learning occurs when action emerges in the context, as the human moves in its environment. The nature of the sensory experience shifts, as we activate or adjust our sensory system with new conditions. Hereby, information such as air pressure, temperature, humidity, wind, sounds, seismic waves, chemical compounds in the air, among other phenomena is processed. Accordingly, humans adapt to their behaviour. Hence, perceptual learning entails an increased ability to extract relevant information from a stimulus array as a result of experience [62]. At any moment, perceptual consequences of the preceding actions inform the planning of subsequent actions. As a result, knowledge is built upon previous conventions, shaped by agency constraints (socio-economic-cultural). However, the fact that environmental information is always present, does not equal its detectability. For example, molecule compounds are invisible to the human eye, yet through breathing and ingestion, we are continuously interacting with them. In this line, the internal human organic defence system codes bad smell with danger or metallic taste with toxicity. From this functional perspective, human life is preserved based on the hedonic evaluation of pleasantness -unpleasantness [63]. Yet, human hedonic and connotative response to sensorial stimuli is variable in accordance within cultural framesets, imbued accordantly with different symbolic values [64]. Sensory studies have shown that sensory perception, beyond being a physical act, predominately is a cultural act [65].

Independently of cultural variances, the "environment-human" communication relationship (Figure 1 – left) presents itself as an intimate relationship without mediators. Fundamentally, it is multimodal and multidimensional, relying on human perceptive and cognitive processes. Such relationship testimonies "Stonehenge", a prehistoric monument from the Middle Neolithic, located in Wiltshire, England. Functioning as an observatory of solar and lunar motions, it served the purpose of a calendar, season marker and ceremony platform [66]. The alignment of the stones allowed to frame astronomical events and perceive the environment in relation to the sky. In this elemental relationship, the whole human sensorial system is applied without mediators. It fuses direct human individual perceptual and cognitive responses to what the environment communicates, within a unique time and space frameset.

2.1.2. The "environment-machine-human" communication relationship

The "environment-machine-human" communication relationship relies on machines that read the environment to inform humans. By machines, we refer to an assemblage of parts or an instrument designed to transmit or modify the application of power, force, or motion. These have a mission to augment or replace human effort to perform a particular task. This is the case of environmental information systems whose mission is to cover the multidimensional features of natural events [30]. These are feed by geospatial data, remote and local sensory networks, as also 3D radar and laser scanning systems. Geospatial data combines objects, events or phenomena that have a location on the surface of the earth, including location, attribute and temporal information [67]. Satellite imagery provides multispectral imagery about land use, vegetation cover, soil type, urban areas, and other elements [68], whereas 3D radar systems collect 3D models of buildings and streetscapes.

Regarding environmental smell and taste monitoring (e.g. [69],[70]), methodologies embrace mixed approaches. These include indirect methods (one hand instrumental detection), direct methods (characterization of smell or taste by referring directly on their effects on a panel of qualified examiners) [21], as also citizen participation (e.g. [72], [73]). Evaluation methods may include human perception variables. For example, smell evaluation reports englobe a list of substances involved and their concentration, as also the hedonic tone and perceived smell strength [74], [75]. Similarly, taste evaluation reports may include the chemical compounds in food products or drinking water samples in line with governance regulations, as also variables such as aroma, appearance, colour, and texture.

In any case, geodata clusters serve always conceptual models that are compiled by sets of physical, biological and chemical indicators [76], [77],[78]. These are observed values that are representative of a phenomenon under study [79] and provide information about environmental quality. They reflect system analyses [79] based on methodological frameworks, which represent an empirical model of reality, but not reality itself [80]. Thereby, official data sets resources [81] provide information for multiple purposes such as planning, modelling, management and governance. Application of utilization comprises weather, flood, pollution and dispersion modelling, water, and urban planning, as also risk and military management. On that account, scientific methodological approach splits the sensory components into data units. Machines operate as components readers and information delivery, in accordance with predefined requisites. In this "machine" mediated communication system, the human sensory multimodal interpretation is lost. As such, the "environment-machine-human" communication relationship (Figure 1 - middle) is mono-modal and mono-dimensional.

2.1.3. The "environment- human/tech" communication relationship

While the primary "environment-human" communication relationship relies on sensorial, perceptive and cognitive processes, the "environment-machine-human" communication relationship relies on machinery and governance for specialized technicians to report them.

Both models represent opponents of a relationship that ultimately requires balance and integration.

We propose the "environment-human/tech" communication that aims to realize a relationship of multimodal intersection, a relationship that attains to reveal what has not been acknowledged as fundamental for human positive purposes (Figure 1- right). We refer to technology, as the application of scientific knowledge to the change and manipulation of the human environment, as it occurs with soft and hardware developments. Regarding human positive purposes, we refer to pro-environmental decision-making. Considering the realm of "environment-human/tech" the intersection we envision environment, human and technology not having to limit functional boundaries. Instead, they inform and operate within a holistic and inclusive ecological system. Presently, the nearest approach of this concept are citizen science-based projects such as "Smell Pittsburgh" [82]. Traditionally citizen science is defined as a research technique that involves public volunteer participation to gather scientific data [83]. Actually, it has evolved into considering citizen science as a fundamental backbone to involve the public in participative design methods of projects addressing real-world problems [84]. In addition, citizen science has been recognized contributing to participatory democracy and active citizenship [85]. Complementary, conceptual practices that reveal the bodies experiences within spatial envelops are relevant interaction scenarios inspirations. The "Climate Dress" [86] uses conductive embroidery to visualize the level of CO_2 while the body moves. "The Light Creature" [87] is a reactive light-emitting diodes (LED) facade based on data derived from the local area, that responds to sounds, air quality and people's interaction with a smartphone app. Both project approach reinforces connecting and discovering of our environment.

Considering environmental information, we envision citizens not only passively interacting with pre-formatted environmental data but also actively to produce personal environmental-related data. Thus, personal narratives complement official ones, allowing knowledge building from an intimate place, where humans are the environmental data themselves [88]. Hence, the preferred **"environment-human/tech"** communication relationship approach is composed of the human sensorial perception system, as also of the scientific information system. Humans are not mere users of technology, rather they are perception vehicles of technology-mediated relationship with the environment, which includes objective and subjective dimensions.

Consequences for design in this context implies thinking about the non-scientific public and its needs to extract and interpret environmental information with all the senses. Concerning our research work, we focus on the chemical senses, as they represent the primer human sensor system processing environmental information through breathing and ingestion.

2.2. The Chemical Senses

The chemical senses are composed by the senses of smell (olfaction), taste (gustation) and trigeminal stimulation compose the chemical senses, which rely on signal transduction by the human brain, and thereby its interpretation. Design strategies that include smell and taste, encounter specific constraints: individuals present inter-subject variability, varying olfactory preferences over time and cross-sensory effect [7]. This is bound to the fact that chemical senses are mainly a physical and a cultural act.

As a physical act, smell is the result of the olfactory bulb stimulation via orthonasal and via retronasal route. Scientific calculations assert that humans can discriminate more than 1 trillion olfactory stimuli [89], even if semantic identification is limited [90]. By "sniffing" air through the nostrils (orthonasal) or by swallowing cavity reaching the back of the throat (retronasal), volatile molecules active receptors imbedded in the olfactory mucosa at the roof of the nasal and neural signals are sent to key areas of the brain involved in speech, emotions, memories and reward [91], [92]. Whereas taste involves sensations that arise from the tongue's taste buds stimulation, which comprise sweet, sour, salty, bitter and umami [93]. On the average 2.000-8.000 taste buds are located on the tongue [94]. Flavour perceptions are generated when smell is fused through the retronasal route with taste information [95]. Additionally, trigeminal stimulation by biting and chewing actions also contributes to flavour experiences. The process temperature, spiciness, body and touch information in the mouth and tongue [96] supplying the brain with information about food choices. Those transduction processes occur via neural pathways to the gustatory cortex, which location neuroscience research relate also to behaviour and survival [59].

As a cultural act, smell and taste perception is imbued with cultural significances [64]. Almost all responses to smell and taste are based on associative learning principles [97]. Sensory meaning serve various functions. As a primary human survival resource, human chemical communication [98] includes food and beverage choices based on nutritional, toxic and hedonic properties. Besides, studies showed that chemosignals communicate through smell positive and negative emotions between humans [99], [100], such as dangerousness [101] and happiness [102]. It also includes interpersonal communication modes, as in case of the inter influence of body smell and mate choice or mother-infant recognition, among others. Sensory symbolism is thereby established through verbal and non-verbal communication by following social signs and structures. Its absorption into the cultural body frames human-world relationships.

2.2.1. The Chemical senses and Environmental health communication

The National Environmental Health Association assures that "Environmental health evaluates hazards to health in the environment, protects all from harmful agents, and promotes health and well-being" [103, p. 73]. Health hazards are environmental media such as physical, chemical, and biological agents in air, water, soil and, food. This "environmental media" is transferred to humans by inhalation, ingestion or absorption. Stress factors of the environment are chemical (air pollutants, toxic wastes, pesticides, volatile organic compounds); biological (disease organisms present in food and water; Insect and animal allergens); physical (noise, ionizing and non-ionizing radiation); and socioeconomic (access to health care). Europe's major environment-related health concerns are related to outdoor and indoor air pollution, poor water quality, poor sanitation and hazardous chemicals. The main related health impacts include respiratory and cardiovascular diseases, cancer, asthma and allergies, as well as reproductive and neurodevelopmental disorders [104]. While governmental programmes [105] are undertaking these problems, its complexity undermines fast solutions. Meanwhile, communication is basilar to acknowledge, inform and educate about environmental health. In this domain an interdisciplinary approach of science, engineering, design and art could yield new perspectives and solutions [106]. This section considers the practices most directly related to this study. The projects listed are related to HCI and the Sensory Arts and Design field [9]. These practices address monitoring, reporting, data visualization, education and behaviour change.

2.2.1.1. HCI projects

Smell Pittsburgh (launched 2016) - The citizen science-based project "Smell Pittsburgh" [82] is a participative system that crowdsources reports to track how pollutants travel through the air across Pittsburgh. Public data reports comprise air quality metrics, self-reported health symptoms and personal annotations such as stories, images and sound. These reports are sent directly to the local health department and visualized on a map along with air quality data from monitoring stations. Thereby, "Smell Pittsburgh" engages citizens to inform, monitor, share smell occurrences. The project proved that engaging residents in documenting their experiences with pollution odours can help to investigate air pollution patterns and can empower them to intervene for better air quality (Figure 2).

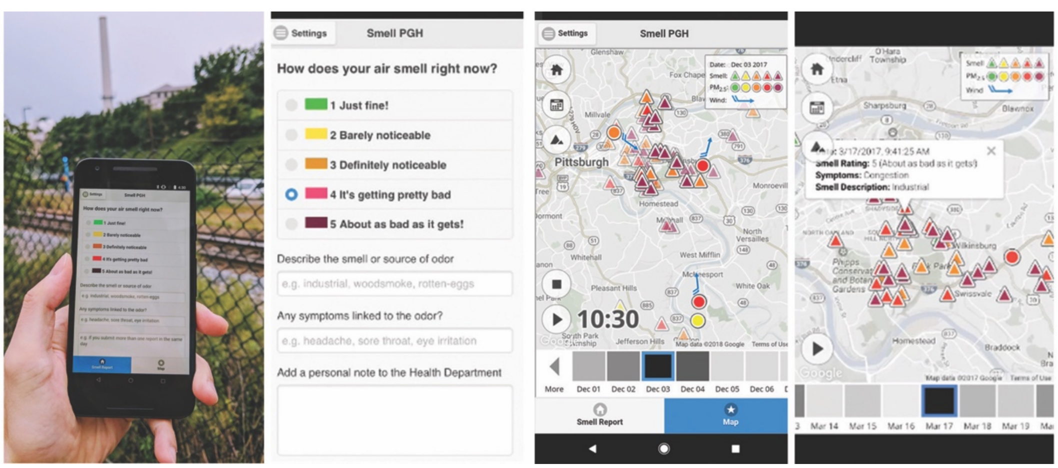


Figure 2 - Smell Pittsburgh app frames (launched 2016)[1].

[1] Screengrap from https://smellpgh.org/ [acessed 14 November 2020].

SmellyMaps (launched 2015) – Geotagged social media hashtags correlated with smell descriptors are visualized as an urban "smellscape" map [73]. The qualitative data enables the user to explore five main categories along the streets of London and Barcelona (Figure 3). Thereby the relative quantity of hashtags from emissions, nature, food, animals and waste are revealed. Specific variables (e.g. industry, transport, cleaning) correlate with governmental air quality indicators Additional features provide emotional dimensions correspondences [108].

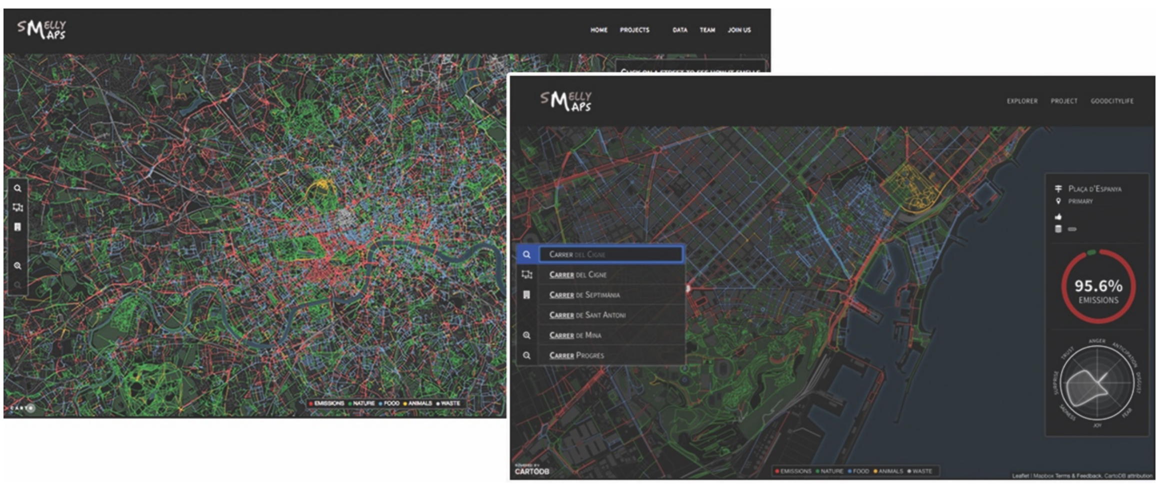


Figure 3 - Smelly Maps data visualization (2015)[2].

ActNow.Bot (launched 2018) - is an interactive and responsive chatbot harnessing Artificial Intelligence to engage people to take pro-environmental action [109], [110]. Launched in collaboration with Facebook platform, the chatbot recommends everyday actions and tracks the number of actions everyone is individually taking by sharing user's progress with followers on social media, it aims to

[2] Screengrap from https://goodcitylife.org/smellymaps/index.php [acessed 14 January 2019].

motivate individual action on climate change and sustainability. Areas of action comprise food and water supply, mobility, energy, farming, plastic pollution and recycling.

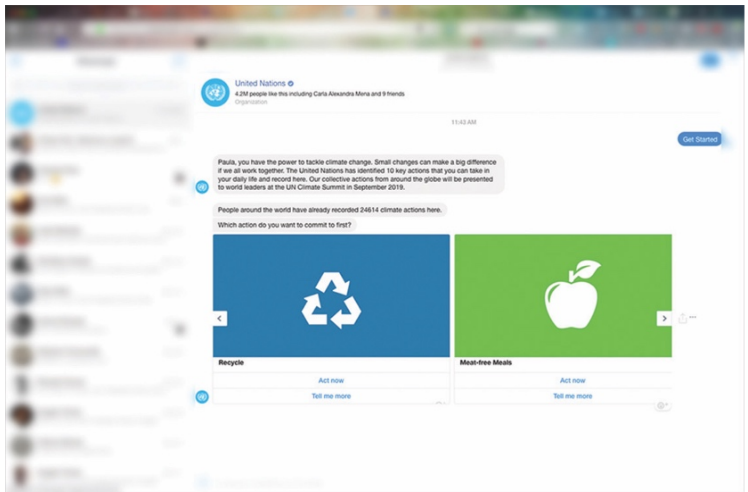


Figure 4 - ActNow chatbot on Facebook platform[3].

Count Us In (launched 2020) - According to the UN Environment Programme [111], 20% of global emissions could be reduced if 1 billion individuals made small changes in their own. In response "Count Us In" campaign [112] was created to engage at least one billion people around the world to act on climate change through practical steps and reduce carbon pollution. "Count Us In" platform invites people to sign up online for the steps they want to take and a level of commitment towards pro-environmental behaviour. Leading themes are food, energy, mobility, finance, recycling and activism (Figure 5).

[3] Screenshot from the author of this work.

Figure 5 – "Count Us In" campaign[4].

Breathe Life (2016) - Breathe Life is a web-based campaign led by the World Health Organization to raise public awareness of the impact of global warming and air pollution [113]. It combines public health and climate change expertise with guidance on implementing solutions in support of global development goals for cities, organizations, individuals and health sector professionals. The campaign instigates to share knowledge, monitoring, supporting solutions and educating people (Figure 6).

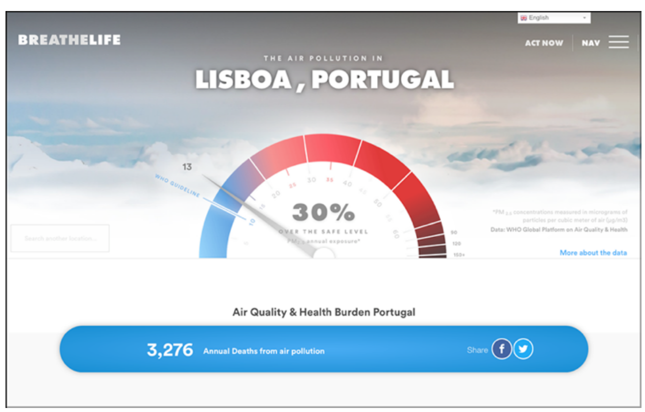


Figure 6 – "Breath Life" campaign[5].

[4] Screenshot from https://www.count-us-in.org/aggregator/[acessed 14 November 2020].ty
[5] Screenshot from https://breathelife2030.org [acessed 14 November 2020].

2.2.1.2. Arts and Design projects

Ocean of Air (2019) – Is a multisensory immersive installation combining projections, interactions and virtual reality created by Marshmallow Laser Feast Studio[114]. The experience invites to acknowledge the symbiosis between humans and plants, as one interdependent ecosystem. For this purpose, the visitor is equipped with a backpack containing a computer and an autonomous VR headset attached to hand motion tracker, breathing sensors and heart-rate monitors. The experience consists of making visible the permanent gas exchange between a tree and a human. Virtual representation of air particles emerges from the mouth, floating around the bodies. In sync with the user's heartbeat, visualization of the oxygen that irrigates the body's blood vessel reveals what happens under the skin. When the giant tree appears, the exhalation is absorbed by the tree, giving back oxygen that is inhaled by the user (Figure 7).

Figure 7 - Ocean of Air installation by Marshmallow Laser Feast Studio[6].

Climate Pod (2018) – Taking inspiration from Buckminster Fullers' geodesic domes, Climate Pod is an immersive installation by Michael

[6] "Ocean of Air" video excerpt: https://vimeo.com/332218848 [acessed 5 March 2020].

Pinsky, made up of five geodesic domes emulating urban polluted environments [115]. Within each dome, safe olfactory blends and fog machines allow sensing the changing air quality of moderate to highly polluted world cities. It starts with breathing clear smelling air of Tautra (Norway) and then continuing through to the cities of London (United Kingdom), New Delhi (India), Beijing (China) and São Paulo (Brazil). Climate Pod aims to raise awareness about air pollution and health in different regions of the world by providing the public with the near to real situation of breathing in distant places (Figure 8).

Figure 8 - Climate Pod immersive installation by Michael Pinsky[7].

Ghost Food Project (2013) - An art installation with collaboration of Miriam Songster which approaches climate change problems exploring food experiences and crossmodal correspondences. It includes a customized food truck, trained performers, synthetic scents and a lab-made olfactory device which is worn on the face and positions a pod with a scented displayer under the wearer's nose (Figure 9). Three taste experiences are offered based on scent-food

[7] "Climate Pod" images from https://www.somersethouse.org.uk/whats-on/michael-pinsky-pollution-pods [acessed 14 January 2019].

pairings that simulate the taste experiences of foods threatened with extinction due to the impact of biodiversity loss. Sensory substitution of the perceived scent combines a facsimile food with a custom-designed synthetic smell. When ordering a taste experience (cod, peanuts and cocoa) from the menu, the visitor expects to get something, which is combined with the simulation via the olfactory device [116]. The ultimate goal is to raise questions about safe food systems and pro-environmental behaviour.

Figure 9 - Ghost Food installation by Miriam Songster[8].

Talking Noses (2010) – An olfactory installation in which Sissel Tolaas presents a subjective representation of Mexico City (Figure 10). The artist tracked down key smells of neighbourhoods and reproduced them synthetically, using headspace technology. These are exhibited in form of a liquid and a scratch and sniff map and accompanied by looping video footage of close up sniffing noses. Only smell description words by its Mexico City residents are heard in the video. The visitor could connect testimonies with the correspondent smell of a specific location. In this manner, the installation aims to translate the

[8] "Ghost Food" performance video: https://vimeo.com/85584034 [acessed 10 July 2019].

invisible olfactory narrative of the city in terms of its identity and health impact, such as air pollution [117].

Figure 10 - Talking Noses installation by Sissel Tolaas [9].

2.2.1.3. Environmental dimensions of smell and taste communication

This review highlights how environmental health communication handles smell and taste, and how chemical senses are represented objectively and subjectively. Project practices demonstrate a range of motivations, methods and representation forms using technology.

Smell interaction based on hedonic evaluation is featured by citizen-science based project "Smell Pittsburgh". The platform offers public participation on smells occurrences by reporting smell perceptions based on a hedonic scale. Data visualizations present standard symbols that reveal the spreading of smell associated with meteorological conditions. By these means, Pittsburgh's public is enabled to have an active role and informed overview of air quality.

[9] Screengraps from https://www.ediblegeography.com/talking-nose/ [acessed 14 January 2019]

Smell visualization based on semantic evaluation is featured on web-based projects “SmellyMaps”. Scents are visualized by colour categories on a map, along street trajectories. In this case, the user visualizes a data portrait of the geographic area, build upon on analyses of semantic classification conventions derived from photographs. Displaying Air Quality information adds functionality and suggests real-time reporting. However, the map representation is frozen by the timeframe when it was built. Displaying physical urban smellscapes are much more refined than at such time fixed map representation, as smells are not fixed grammar objects, but are volatile plumes.

Smell and taste interaction based on emulation, transferability and empathy is featured by “Talking Noses”, “Ghost Food”, “Climate Pod” and “Ocean of Air” projects. These projects apply technology to reproduce environmental situations and create empathy as a mediator of critical thinking. Making the invisible, visible thrives designers and artists to develop alternative creative practices. “Talking Noses” combines headspace technology to emulate geolocated scent sources. The smell experience is contextualized by video footage, photography, and map visualizations to deliver an intended message. Olfactory artist Sissel Tolaas applies smell as media to convey transferability into cities neighbourhoods and its condition. “Ghost Food Project” also combines several media to deliver the conceptual narrative baseline. Technology here is applied to trick the brains’ sensory interpretation, of what is simultaneously smelled and ate. The concept relies on subjective food experiences as initiators of objective problem-solving. “Climate Pod” offers the opportunity to mingle with distant atmospheric habitats and engage with visitor’s whole-body sensory perception. Technology is applied to emulate the environmental air quality condition through smell, temperature, humidity and colour. By the breathing and sensing the air the human sensory system immerses into its symbolic representation. Hence, an individual’s natural physical and emotional reactions, open space for environmental awareness and discussion. Likewise, “Ocean of Air’s” conceptual execution focuses on the human breathing system as a mediator of immersion. However, technology here is applied to trick the brain’s sensory interpretation through the visual system. By synchronizing objective biometric data and with subjective visual representation forms, the user is transferred into a virtual scenario where the message is unfolded. Beyond providing an aesthetic experience, it aims to trigger environmental consciousness.

Smell and food interaction based on pro-environmental action coaching is promoted by “ActNow”, “Count Us In” and “Breath Life” campaign. We call “action coaching” the trend of the latest communication practices to emulate a dynamic interpersonal conversation with the user by tracking and coaching their behaviour. “The more people act, the bigger is the impact” is the conceptual baseline of these emergent web-based sites, mobile apps and chatbots, addressing individual and collective behaviour. The campaigns provide environmental information and education offering support to setting and pursuit pro-environmental goals, presented as impact calculations by data visualization.

This review lets as conclude that environmental dimensions of smell is mainly related to air pollution, while taste is associated with food safety. Moreover, the main strategic areas considered include:

- Monitoring practices
- Context related information
- Environmental education
- Participatory citizenship
- Pro-environmental Action Coaching

2.2.2. Chemical senses and Multisensory HCI design

The earliest technological device to employ smell was “Sensorama” in 1962. Heilig [118] designed an arcade-style device which took users on an immersive 3D virtual reality bike ride experience through the streets of Brooklyn, New York applying beyond vision also air, smell, sound, and vibration. Movie theatres made a short experimental incursion on cinematic smell enhanced experiences in 1959. Image synchronization with smell was conveyed by the system “Aroma-Rama” using ceiling vents. Whereas, “Smell-O-Vision" system used plastic tubes piping smells to the individual dispenser on the back of every seat [119]

Human-world experiences combine multiple sensory information input and output from the smell, taste, vision, haptics, and sound modality channels. While we increasingly expect technology to replicate these experiences, we observe that interactions with technology are dominated by visual, auditory, and, eventually by tactile interfaces [120]. Obrist et al [121], [5], [25] identified this gap and has developed studies to emphasize how taste and smell inclusion with interactive technologies is of major importance for future multisensory experiences that could potentially have an impact on society and consumer markets, creating an entirely new product, technology, and service opportunities.

Above all, multisensory experience challenges interaction paradigms within the field of Human-Computer Interaction (HCI), as they propel the understanding of the human senses as interaction modalities. However, as much the mission is appealing, its compliance is not granted as “(…) there are still many challenges when it comes to studying taste and particularly smell, especially related to interindividual variability, varying olfactory preferences over time, individual sensitivity and allergic reactions to chemical stimuli, and the relative importance of crossmodal influences”[121, p. 3]. Recognizing a cross-disciplinary framework as crucial, the authors recommend neuroscience, psychology, and sensory science as knowledge providers, especially in relation to the chemical senses [6].

2.2.2.1. Multisensory HCI design

So far, HCI research community has focused on the question of “how” to stimulate the sense of smell and taste, and not so much on the “what for”. As an evolving field, HCI chemical sense inclusion efforts [25], [122], [123], have tackled the digitalization of smell and taste for delivery, transmission or induce sense substitution [124], [125]. Recently, technology advancements have allowed to expand chemical sense inclusion possibilities in digital media [25], [7] and to envision its applications [126]–[129]. Interactions system of smell and taste interfaces have been further explored via chemical, electrical, thermal or acoustic levitation systems [130], [131]. Overall, digital smell is carried out in training, health, and entertainment devices, while digital taste remains broadly in the research stage.

Smell. Most of the methods used for smell experiences are based on stationary and wearable devices [132], [133]. Stationary systems assuming the user’s passively receiving the smell are virtual olfactory displays delivering ambient scents by chemical stimulation (molecules) released under computerized control e.g. [134]. Stationary emissions assuming user’s action to initiate the smell delivery process are systems where the user has to move the device towards their nostrils [135]. Alternatively, smells might be perceived by electric stimulation of nasal nerves. However, its emission mode is not yet explored. In regard to wearable devices, these allow to direct scented air to the user’s nose and are mainly applied as notification systems.

These systems are available as mobile scent dispensers attached to smartphones [136]–[138], accessories [139], [140], or even garments [141],[142].

Comprehensible reviews have brought insight to olfactory phenomena within the realm of HCI in terms of application [143] and evaluation methodologies [144]. Challenges have been identified, as also its limitations [7]. Promising applications appeared in marketing for persuasive communication [145], in health for disease diagnosis and mental wellbeing [146]–[148], as also in education for information processing [149] and enhanced performance [150]. Applied to virtual training, smell stimuli stimulates productivity and physical performance [151]. Smell enhanced technologies where also explored on multimedia applications [152], ambient displays [136]–[138], [153], [154], gaming [155]–[159], virtual reality [135], [160], [161], military training [162], [163] and simulated driving [164], [165]. When it comes interacting with smell within a space, experiments englobes exhibition design [166], [167] and architectural spaces tuned with "fragrance collages" [168] moving towards more refined interaction space methodologies [127].

As communication systems, Kaye's [169], [170] pioneering study about the symbolic olfactory display, challenged the HCI community to consider application possibilities with smell as media. Kaye linked smell to functional notifications systems, that when associated with text, image or sound aimed to deliver recognizable subjective messages by the user. Bodnar et al. [171] explored smell as a notification mode and showed that smell is less effective than visual and auditory modes, but also less disruptive. Seah et al. [129] combined sight and smell in a projected mid-air display of bubbles. These are filled with fog that contains a scent in accordance with the notification. The user can smell the notification by bursting the bubble. Warnock et al. [172] studied smell notification on older adults envisioning multimodal reminder systems for home care. Dobbelstein et al. [173] designed a wearable olfactory display that allows the user to receive scented notifications, that are coined as “scentifications”. Brewster et al.[150] developed a system which allows the user to tag digital photo collections with smells. Other studies have explored smell interaction to foster social interactions [174], [175]. Electric smell transmission over the internet accomplished by Ranasinghe et al. [176] uses a tumbler embedded with electrodes and led. Cheok et al. [177] propose electric smell interfaces using electrodes in the nostrils to deliver electrical currents above and behind the nostrils.

Taste. Methods of delivering taste experiences are achieved by chemical stimulation [125], (LOLLio) [178], electrical or thermal stimulation (Ghost Taste) [179], (Virtual Lemonade) [180], [181], and by the novel acoustic levitation interface (TastyFloats) [131]. Overall, these experiences are provided by liquid or solid chemical compounds which seek to deliver specific tastes [182]. Hence, the five basic tastes (sweet, bitter, sour, salty and umami) are reproduced by using glucose for sweet, citric acid for salt and monosodium glutamate for umami [125]. Taste dispensing mechanisms inspired by everyday objects such as a Murer’s “Lollipop” [178] or Ranasinghe’s electric spoon [181] apply this method. Alternatively, Maynes-Aminzade (TasteScreen) [183] proposes interaction by placing plastic cartridges on a screen, which releases the smell if the user is persuaded to lick these. Whereas the electrical or thermal stimulation approach implies to stimulate the tongue papillae [184], [185]. Electrical stimulation is achieved by placing a silver wire on the top of the tongue and an electrode on the user’s wrist or hand [179]. While the thermal stimulation incites taste by the stimulation of the mouth and surrounding area [185]–[187].

This review summarizes interaction design approaches that explore input/output - stimuli/feedback paradigm. Yet, interpretation outcomes are determined by the intersection of cross-modal correspondences. Kerruish emphasizes how "(…) design practices in digital taste and smell suggest that not only are the technicalities of stimulating receptors important but so is the broader perceptual context."[188, p. 34] In this realm morphology and cross-referencing are practiced to shift thresholds of perception and provoke taste and smell, taking advantage of being "embedded in a culturally situated corporeality" [188, p. 34].

2.2.2.2. Multisensory HCI Experiences

Cognitive Sciences defines crossmodal correspondences as the tendency where signals of one sensory dimension are associated with signals of a different sensory modality[189], [41], [190]. Rooted in experimental psychology, crossmodal association research offers insights on how sensory modalities relate and influence each other [40], [41]. These include associations that involve simple basic stimuli such as visual brightness or auditory pitches or complex stimuli such as abstract forms or linguistic metaphors. In that regard, cross-modal effects [128], [191]–[193] influence multisensory design frameworks. Examples englobe visual-auditory influences on spatial perception [194], [195]; visual forms influences on semantic attribution [196]; smell hedonics influences on visual attention [197] and auditory and colour influences on taste perceptions [96], [198]–[201].

These and similar studies, clarify that sensory modalities do not work as independent models and that they are not ruled by a vision dominant hierarchy. So far Multisensory HCI application englobes entertainment [120], [128], [202] and accessibility [203], [204]. However, the more understanding of chemical senses handling increases, the more it is expectable new concepts and possibilities to emerge. Narumi's "Meta Cookie" [205] is a pioneering project based on crossmodal effects, that accomplished augmented taste experiences using augmented reality (AR) and smell. While holding a cookie with an AR marker, the user wears a head-mounted visual and olfactory display. A webcam attached to the headgear detects the marker on the cookie while visual settings are changed, in order to substitute the image of the cookie the person sees through the display, to a different texture and colour appearance. The “real” cookie morphs visually to a “different” cookie, interpreted by the brain in accordance with the delivered smell. Whereas, Hashimoto et al. [206] developed the “Straw User Interface” (SUI) exploring the hypersensitivity of the mouth and lips. The system presents an audio-tactile interface in the shape of a straw, that let the user virtually experience the sensations of drinking. These are achieved by sample data of actual pressures, vibrations, and sounds recorded during drinking from an “real” straw. Ranasinghe et al. [207] “Vocktail” simulates multisensory flavour experiences digitally through an interactive drinking utensil with the shape of a cocktail glass. It applies electric stimuli and combines of taste, smell and visual sensory modalities to create the illusion of virtual flavours "of a beverage. Regarding food texture simulation, interface concepts uses haptic or auditory information. Food Simulator [208] is a haptic interface that generates a force on user’s teeth combined chemical, auditory and smell inputs to deliver food texture perception. “Chewing Jockey” Is a system composed by bone-conduction speaker, a microphone, a photo reflector to measure the motion of jaw, and a computer to design the sound effect [209]. The system captures and enhances eating sounds augment food texture. As the user bits, chewing sounds propose to enhance food experiences.

This review testimonies the challenges involved when designing *with* and *for* the chemical sense interaction. As an evolving field of practice, application domains such as entertainment [120], [128], [202] and accessibility [203], [204] have fostered knowledge building. Despite overall experiments proved technological feasibility, Spence et al [7] has highlighted that its limited dissemination is depending on relevant consumer centred applications. However, the chemical sense properties undermine the global business model approach based on repeatability and escalation. For example, smell is perceived differently considering by human characteristics such as age, nationality/culture, gender, mood and life experiences [210].

Summing up, Obrist's [122] seminal appeal to the HCI community to reflect about which sensory experiences we can design for, how to manage sensory associations, and what frameworks to develop, are still valid. Meanwhile, plausible future scenario explorations, as human-food interaction for space travel [193], present new and creative ways of integrating multisensory interaction.

Multisensory experiences are defined by Velasco and Obrist as "impressions formed by specific events whose sensory elements have been carefully crafted by someone" [211, p. 15]. In relation to our study, the multisensory experiences take advantage of the human body as the primer sensor system to process environmental information through the senses of smell and taste. Comparatively our approach integrates *"specific events"* as the events provided by the spontaneous environmental context, the *"sensory elements"* are every-day smell and food ingredients and *"craft"* execution is tied to design components applied in accordance with the design intent.

2.2.2.3. Section overview

In this section we have reviewed literature and listed design projects to investigate the main research questions RQ 1:" How can the chemical senses be included in digital media design?" and RQ 2: "How can the chemical senses communicate environmental heath on digital platforms?"

Having analysed how the environment-human communication relationship has evolved and mediated by technology, we concluded that the chemical senses are potential mediums to be applied by the preferred environment-human/tech communication relationship. Considering a range of projects in the Science and Engineering field as also of the Art and Design field, we analysed what methodological practices were applied to communicate, uncover and act on environmental problems, through the senses of smell and taste. We observed that tendentially smell occurrences are associated with air quality problems. However, dangerous smells might be odourless. Moreover, pleasant environmental smells are important references for our habitat and should be considered in a system. Similarly, taste is tendentially related to toxicity detection or to diet habits. But beyond factors of nutrition, taste perception also assesses factors of environmental geo-location information. In other words, breathing and digesting are carriers of environmental health narratives [212]–[214].

Our research identified a lack of smell and taste representations as digital forms, especially regarding individual perception communication. Past attempts of digital representation of those senses as communication systems have shown limited success [192], [215]. We realized that there is also a lack of meaningful Multisensory HCI solutions that explore the chemical sense interconnection with the environment as a vehicle of environmental communication, and consequently as a mean of environmental education.

In the following Part Three, we disclose the Multisensory HCI design methodology and practice that we developed, to remediate this situation. We present two design hypotheses that we projected as proof-of-concept. Within this realm, is where our work contributes to moving design practices forward.

Part III - The Design Project Experiment

"Now, in July 1980, at eighty-five years of age, I have consumed over 1000 tons of food, water, and air, which progressively, atom by atom, has been chemically and electromagnetically converted into all physical components of my organism and gradually displaced by other income atoms and molecules. Now all but 146 pounds of that 1000 tons have been discarded."[216, p. 343]
R. Buckminster Fuller, 1981

3. Introduction

This section describes our exploratory study which aims to demonstrate how chemical senses allow representing environmental problems within digital forms and how Multisensory HCI Design can be applied to communicate environmental health.

Based on the recognition that human health and well-being are intimately linked to the state of the environment, raising environmental knowledge within communities and citizens is crucial to pursue mitigation and adaptation to changing environmental conditions. We aimed to render these pieces of evidence eye-visible. In any given breath we take, the fact is that we share all molecule components that shape our every-day life as illustrated by Kean[217] and Gilbert [218]. Likewise, with every human sensorial action, we are affecting the molecular ecosystem and human social relations. Sloterdijk [219] reminds us how chemical weapons applied as military strategies are tied up with the invisible destruction of our living environment. Furthermore, he outlines that "(…) in the age of atmospheric toxins, strategies, and hidden agendas all (…) quasi-religious consenting to place one's trust in one's primary surroundings - be it nature, the cosmos, creation, homeland, situation, etc. - takes on the guise of self-harm"[219, p. 108]. "Having become aware of the primary and secondary greenhouse effects, living and breathing under open skies can no longer hold the same meaning as before" [219, p. 109].

We named the project "*Earthsensum*" by envisioning humans' as the main device, sensing the Earth as an "Interface" with a collaborative HCI system aligned with the "environment-human/tech" relationship. We designed its Visual Identity based on these concepts (Appendix D1 - Figure 45, Figure 46).

Our Multisensory HCI Design process entailed the second main research question:

RQ2: How can the chemical senses communicate environmental health on digital platforms?

To accomplish this goal, we formulated secondary research questions:

- **RQ2.1.: How can the chemical sense be applied to inform such a system?**
- **RQ2.2.: How is the design strategy of such Multisensory HCI Experience?**
- **RQ2.3.: What is the impact of this Multisensory HCI Experience on Users?**

By answering these sub-questions, the *Earthsensum* design process progressively unfolds.

3.1. Multisensory HCI Design Methodology

Our methodological approach is "research through design" within HCI domain [37], based on hypothesis formulation [42]. It is an active research form that connects the unpredictable strategies designers embrace and assist the creative process of solution-searching as research. Research through design is a rigorous method in which design thinking and action profits from "unique insights gained through design practice to provide a better understanding of the complex and future-oriented issues in the design -field" [50, p. 1]. Godin and Zahedi conclude "the designer/researcher is using the project as her or his field for data collection and the validity of the choice of this field comes with the success of the design project" [50, p. 7]. Hence, "(…) if the project works and the artefact produced is acceptable, then knowledge produced through the process is also valid" [50, p. 7].

Earthsensum design process involved ideation, concept development, and prototype experimentation. These design activities pursuit knowledge production through operation, reflection and analyses. As the project focus includes the chemical senses, we approached Multisensory HCI design. As a still-evolving framework, we adapted our methodology based on Haverkamp's Synesthetic Design [43]. The author differentiates conventional design practices optimising each sensorial modality separately from *"the conscious design of objects with respect to connections between the modalities"* [43, p. 15]. In his vision, strategies of connection should be identified before the traditional activation points are selected. The process implies a first stage of "*selecting those strategies which enable connecting modalities with respect to the intended product*" [43, p. 16], followed by a second stage in which these strategies are fused into the product conceptualization.

Concerning the aforementioned stage, Haverkamp's design methodology builds up along two main "construction layers". The first is the crossmodal analogy and symbolic layer, upon which the second layer of meaning and communication is built. The more cross-sensory correlations are optimized congruently and consistently with iconic features, symbols and semantics, the more a functional design experience is achieved with success. Hence, this approach embraces perception and cognition as complementary agents to propose the function and meaning of a design experience (Figure 11).

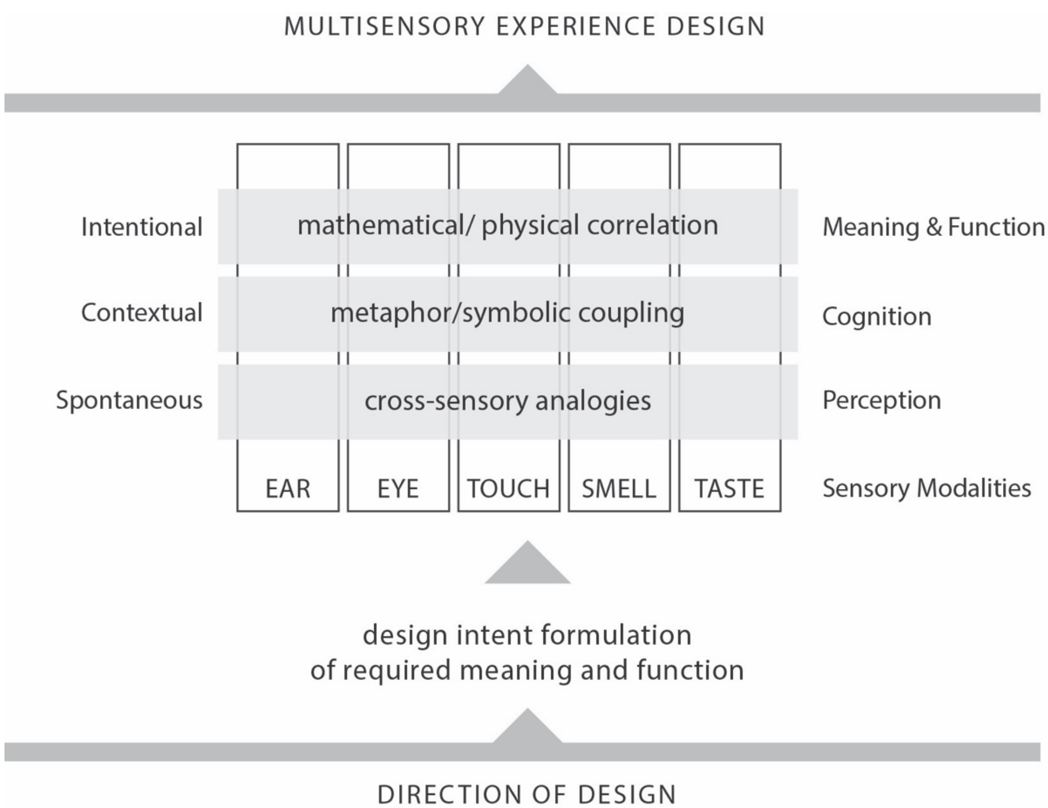


Figure 11 – Adapted Multisensory Design Methodology principle based on Synesthetic Design.

3.2. *Earthsensum* design rationale

Framing the project and its scope, we formulated the design rationale statement to guide our design process:

The chemical senses, elements and places are in a continuous relationship with the environment. As the world is compound by atoms and molecules, humans and environment exchange these through breathing and ingestion. Breath and food are then vehicles which transfer into human blood cells not only oxygen and nutrients, as also air, water and soil conditions of the environment. We presume that the communication of this intertwined environmental-human health relationship could lead to enhanced environmental literacy and foster behaviour change. The role of technology is to support the non-scientific public to interpret, explore and even protect its fundamental multisensory experience.

In accordance, we planned the design process of *Earthsensum* along two main stages: the concept experience and the concept evaluation. The first stage englobed the chemical sense exploration and prototype interaction. The second stage concludes the proof of concept by addressing its concept evaluation.

Thus, considering the first stage, *Earthsensum* methodology englobes two project phases. *The* first phase offers environmental smell and taste experiences about real geolocations without contextual clues. It comprises exploring crossmodal associations for digital representation purposes. The second phase provides the contextualization of the experience for meaning-building. Strategically, we opted for Mobile Virtual Reality (MVR) and Mobile Augmented Reality (MAR) technology, as they supply technical features which support our design intent. This phase comprises prototype development for the final proof-of-concept evaluation.

3.3. *Earthsensum* design hypotheses

To proof our design concept baseline's assumptions, we formulated two design hypotheses. The conceptualization of each hypothesis includes the strategic parameters that we identified in our literature review (Part II): monitoring practices; geo-contextual information; environmental education; participatory citizenship and pro-environmental action coaching.

3.3.1. Design hypothesis 1

An educational tool exploring immersive technology provides virtual tours to environmental hazard locations related to smell or taste experiences. Its mission is to transfer the user into remote places where environmental problems happen. By having tasted or smelled an ingredient, to which its related remote location the user is transferred, we assume it is possible to establish an association between a geographic location and the chemical senses. The system provides a symbolic representation feature allowing the user to volumetrically build sign-objects of his sensorial perception. This association experience is complemented with additional meaning layers. These are delivered by multimedia contents, addressing topics such as cultural conditions, human life impact and prevention measures.

3.3.2. Design hypothesis 2

Building a symbolic representation tool of smell and taste experiences enables to articulate cognitively an otherwise volatile perception. By providing a symbolic representation system, these personal chemical sense experiences can be communicated and shared with wide audiences. In this line, augmented reality technology allows to index smell and taste representation by geographic coordinates and link these to geo-context driven information. Thereby, the platform has the ability not only to provide chemical sense annotation facilities but also deliver local related environmental health information. Hence, the content design addresses multi-purpose objectives: information, education and behaviour change.

3.3.3. Proof of concept assumptions

Considering design hypothesis 1 and design hypothesis 2, we believe that:

- User engagement with these interaction experiences fosters comprehension about the interdependencies between the chemical senses and environmental events;
- A symbolic representation system enables chemical sense education and communication on digital platforms;
- The chemical senses can be applied to communicate environmental health;
- Multisensory HCI Design methodology offers a valid framework to design experiences for environmental health communication with the chemical senses.

Positive evaluation results of our conceptual design and impact on environmental awareness would prove if we were right.

3.4. Design principles and challenges

Our goals are (i) chemical sense communication, (ii) symbolic representation of chemical sense experiences (iii) environmental education and behaviour change. Each goal yields a set of design challenges.

3.4.1. Design for open interpretation

We state that designing multisensorial experiences is equivalent to designing for "open interpretation" systems. In other words, the inter-subject interpretation variability has to be contemplated without compromising the design mission [220]. This represents a design challenge, as chemical sense perceptions are subjective, volatile and temporal. *Earthsensum* integrates two design dimensions that express these permeable properties.

3.4.1.1. Associations: Crossmodal correspondences

Scientific research about associations across the senses started with early experimental psychology investigation in the XIXth century [221]. Nevertheless, research on the systematization of crossmodal correspondences is still underway. Probably because human information processing is not crystalized after its elaboration, reflecting an interactive process of adaptation and interpretation of income signals. Resulting from neural mechanisms, crossmodal processing is characterized by associations between different sensory properties, which provide complementary information and thereby might spur congruency effects.

Studies have shown that smell and taste associations are mediated by affect [222]. The hedonic evaluation with its implicit approach/rejection reaction, is part of an intuitive human decision mechanism towards all types of stimuli. Consequently, pleasantness property plays a prominent role in linking sensory modalities [119]. In the food context people associate taste and colour, acoustic cues, shapes and haptic responses [223], [224]. While in the smell context similar phenomenon can be found [225].

Spence [226] summarizes five main classes to explain crossmodal correspondences:

(1) Structural correspondences:

Certain correspondences result from structural similarities. Example of this correspondence is when the human brain translates more intense stimuli of one sense across all sense modalities.

(2) Statistical correspondences:

These occur from the internalization of repeating events, that is the statistical regularities of the environment. Hence, they may emerge as a result of associative learning Example is when a cup is associate to the taste of its content.

(3) Semantic (or linguistic) correspondences:

Crossmodal correspondences that emerge from consistent use of the same terms for qualitatively different sensory perceptions, might support the linking of sensations across the senses. Example are smell descriptions of fragrance notes in terms of elevation (high or top note).

(4) Use of the availability heuristic:

Certain crossmodal correspondences result from the available heuristic. An example is when a sensory perception is matched by personal interpretation resources, such as mental imagery.

(5) Affective correspondences:

Crossmodal correspondences that arise from evoking a common emotion or feeling across distinct sensory modalities. An example is the hedonic response of colours and emotion.

3.4.1.2. Labelling: Classification systems

As a language, sensory perception and emotion are processed by brain structures, it is expected sensory words to have linguistic reflections. However, in general, we have limited vocabulary to describe our smell and taste experiences and a generally accepted classification schemed does not exist [227]. As Kaye [215] identified, common classification and description schemes of perfume, wine and beverages industries, are not adequate when transferred to interface design.

Classification schemes may help to overcome vocabulary limitations, but they just offer a methodological approach based on agreements. Käppler [90] showed that perception-based arrangements are influenced by variables such as study design, sampling and data analyses. Furthermore, subjects classify a mental representation of a smell that is shaped by various interactions between smell characteristics as well as the impact of interindividual differences in age, knowledge, culture, and so on. Finally, linguistics and semantic arrangements by sensory source have also affected sensory classifications, rather the sensory characteristics.

In this context, western flavour lexicon offers limited semantic representations [228]. Smell descriptions are redundantly described by its *source* and *effect* [229], an approach that suits scientific methodologies such as the smell of drinking water, wastewater, compost and the urban environment [230]. By contrast, when observing non-western traditional cultures, alternative a more enhanced sensory vocabulary emerges. An example is the smell lexicon of Maniq, a language spoken by a small population of nomadic hunter-gatherers in southern Thailand, which is organized based on its multidimensional cultural structure and includes concepts such as *pleasantness* and *dangerousness* [231].

Insofar the pursuit of standardization parameters [232] and universal terms [233] supports scientific methodology, it does not embrace the spectrum of human sensory communication needs. Concluding, designing *with* and *for* the chemical senses implies to contemplate the human interpretative processes and its variances. As much systemization is useful for standardization, it does not reflect the human sensorial experience which defies predictability.

3.4.2. Designing a symbolic representation system for smell and taste perceptions

By providing a symbolic representation system for smell and taste perceptions, we intend to enable subjects to code their experiences with abstract symbols. In this way, translation of his perception is "materialized" in mind and thought and consequently communicated. Umberto Eco [234] defines a sign as everything which can be taken as significantly substituting for something else. At the moment in which a sign stands in for it, this "something else" may not exist or be somewhere. A sign stands for an object or concept, which is transformed into knowledge by processes of meaning construction, such as signification and interpretation. This implies that sign production is established on previously socially recognized ground. When these processes are established as rules and accepted as a socio-cultural convention, a functional code system is settled.

The difficulty arises when one must determine the properties of an object that has not been recorded by culture, due to its characteristics or structural complexity. In this case, the transformation process into an expressive continuum is challenged. Eco describes this meaning production process as "invention" [235]. In this case, the dominant elements are selected from a perceptual field which is not yet organized and are structured as perceived. Finally, the abstractive processes transform what has been perceived, into semantic representation through a cluster of independent expressive units. It is only after having realized the physical expression of the perception taking shape, that in turn allows to progress from the perceptual model to a unit of meaning. Hence, this condition precedes the requirements to ground new sign productions.

This formal background inspired us to conceptualize the design of a symbolic representation system based on graphic and haptic components.

3.4.2.1. Graphic representations

Starting from the light that enters the eyes, surroundings are perceived by colours, patterns and structures. Within this context, we looked into Gestalt psychology research [196] for non-verbal communication processes. Graphic components associations, like shape and colour, enable the construction of meanings [236] through gestalt grouping principles. Simple geometric shapes are imbued with symbology. Examples are downward-pointing V's are perceived as threatening and curvilinear forms are perceived as pleasant [237]. Colour Psychology studies shoes how colour is the meaning carrier, impacting affect, cognition, and behaviour. Despite colour symbolisms are context-specific leading to different implications [238], they can be applied to categorize feelings. Plutchik [239] conceptualized an emotional intelligence tool in the form of an emotion circle and a colour wheel, representing the different intensities and variances of basic emotions.

3.4.2.2. Haptic representations

Similarly, volumetric shapes and textures have the potential to represent multisensorial perceptions, as tangible symbol system research [240] has shown. Dematte et al.[241] studied smell and tactile association rating the roughness of fabric materials considering lemon and animal smell. The participants in the study rated fabrics as softer when the more pleasant lemon scent was presented as opposed to the unpleasant animal scent. The study concluded that smell characteristics can alter tactile perception.

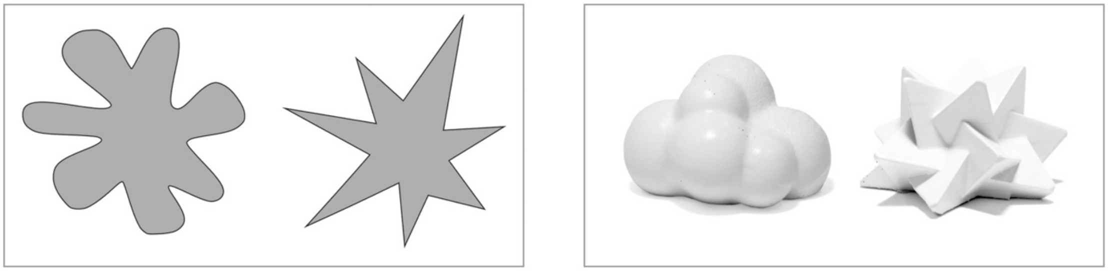


Figure 12 – Left- Picture used in "Bouba/Kiki" effect replicating Wolfgang Köhler's test. Right - 3D printed models of the corresponded "Bouba" and "Kiki" tangible stimuli created by Metatla et al.

Gestalt-psychologist Wolfgang Köhler [196] pioneered the experiment *"baluba/takete"*, which proved that people associate jagged shapes with a sharp vowel sound and soft shapes with the rounded vowel sounds (Figure 12 - Left). Based on Köhler's experiment, Etzi et al [242] studied crossmodal correspondences between tactile sensations, the sound of non-words, and emotional states. Tactile textures comprised samples of cotton, satin, tinfoil, sandpaper, and an abrasive sponge. Smoother textures were associated with round-shaped sounds, words as "quiet" and "feminine" and emotion labels as "relief" and "pleasantness". Rougher textures were associated with sharp-transient sounds, words as "loud" and "masculine" and emotion labels as "anger" or "disgust". The results revealed that tactile textures are associated with words and mental images related to emotional states and that the tactile roughness is the sensorial link of these associations. Metatla et al. [243] adapted Köhler's "Bouba/Kiki" experiment, to study crossmodal correspondences between smell, tangible shapes and emotions in children (Figure 12 - Right). The study confirmed that lemon scent is associated with angular shapes ("Kiki") and arousing emotion. Whereas, vanilla scent with round shapes and calming emotions.

3.4.2.3. Concept application

In compliance with the "environment- human/tech" communication approach, we envision HCI design concepts that foster application possibilities based on mixed and immersive technology. Both interaction concepts are focus on the domains of chemical senses and environmental education.

Augmented Reality.

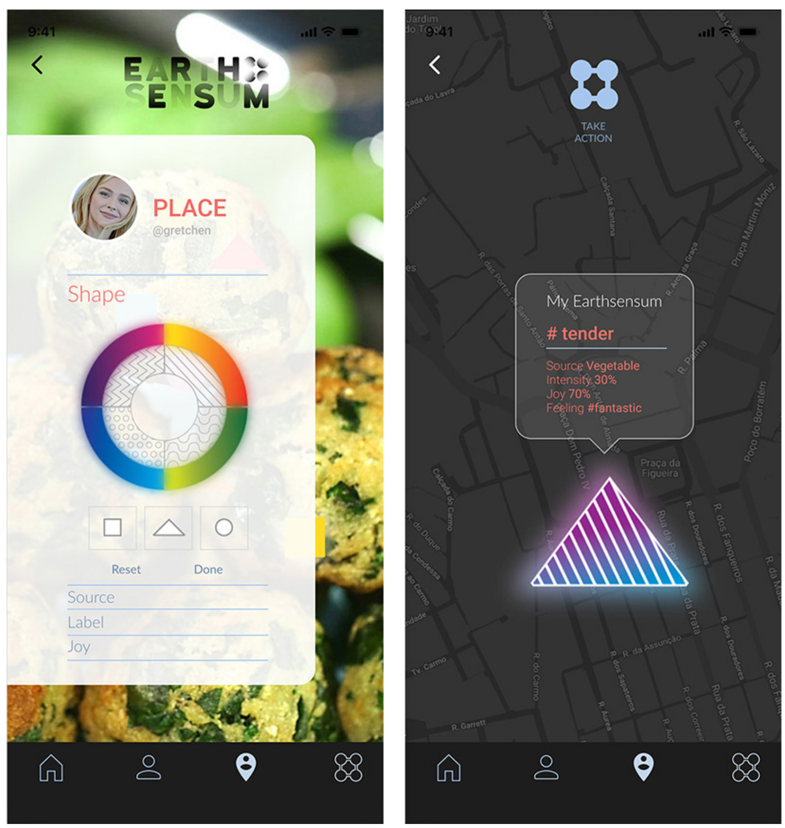


Figure 13 - Interface design concept for Augmented Reality displays

By combining abstract formal associations with hedonic and semantic descriptions, local smell and taste annotations can be performed for an individual or collective mapping purposes (Figure 13). Further information layers through internal and external links ensure, experience contextualization. Hence, our graphic component association concept allied with augmented reality technology allows the construction of geo-contextual sign systems.

Virtual Reality.

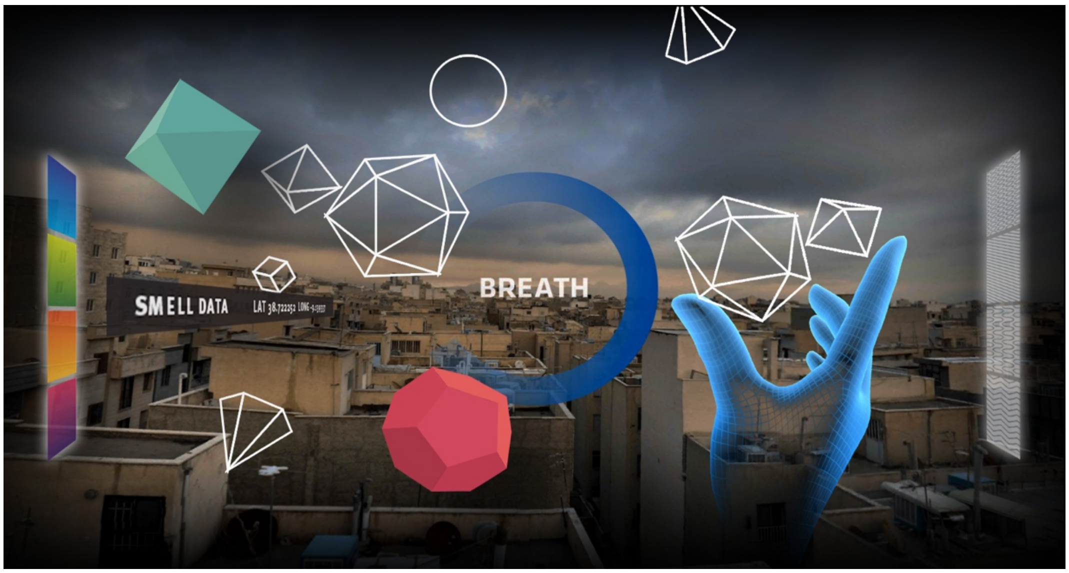


Figure 14 - Interface concept for Virtual Reality display

The haptic component association concept combined with virtual reality technology enables to build abstract volumetric representations of chemical sense experiences (Figure 14). When combined with congruent content development and immersion features, the building of meaning is reinforced. Through these techniques, symbolic representation is linked to a geographic environment which can be local or remote, with a story to tell. Stories assist communication formulations in design [244], [245] and prove to inspire more likely empathy and creative thinking.

3.4.3. Designing for pro-environmental behavior and HCI

Environmental behaviour is defined by Steg “as all types of behaviour that change the availability of materials or energy from the environment or alter the structure and dynamics of ecosystems or the biosphere”[246, p. 309]. Pro-environmental behaviour represents individual conscious actions intending the lowest environmental impact results or even benefits the environment. Psychologist Albert Bandura [247], [248] describes pro-environmental behaviour as a reflection of self-regulatory activity. Thereby our personal beliefs determine how we monitor, judge and react. Hence, self-regulation is associated with perceived self-efficacy, which represents individual beliefs about personal competence to produce performance levels that exert influence over events and that affect his life. Hence, motivation to intentionally perform consistent actions through time, are influenced by the outcome impact beliefs. These expectations are shaped by individual and social effects. Example of outcome expectations shaped by individual effects is health maintenance. Whereas an example of social effects is recognition and acknowledgement from others. From this perspective, individuals are influenced by internal and external factors of their circumstances. They are not only reactive but they are also proactive and consequently become *"products"* and *"producers"* of their environments [249].

Following this theoretical concept, in the field of HCI Design and Environmental Health Communication individuals are "products" when they consult environmental information, such as weather reports to decide what to wear or air quality indexes to prevent some asthmatic condition (information strategies). Likewise, individuals are “producers " when performing an action which delivers an effect on the environment, such as choosing services of sustainable mobility or local food products (structural strategies). On a psychological level, scholars recognize that environmental *internal locus of control* - the perception that one's behaviour directly impacts the wellbeing of the environment -, is a significant trigger of environmental behaviours [250].

From our perspective, the appliance of immersive technology is particularly suited to favour this psychological aspect. Ahn et al [11] showed that environmental messages have more probability to address *locus of control* when delivered with immersive technologies than traditional print or video media. Taking on the topic of deforestation, the interactive task asked participants to engage with a haptic joy-stick to cut down a virtual tree. This rich perceptual experience leads individuals to engage with future negative consequences of "their" action and consider pro-environmental behaviours. Psychologist Linda Steg [246] recommends effective intervention strategies to promote pro-environmental behaviour, as the ones that perform information strategies (information, persuasion, social support and role models, public participation) and structural strategies (availability of products and services, legal regulation, financial strategies). These strategies aim to provide the necessary tools and motivation for an individual to perform the desired behaviour.

We assume that HCI experience design is relevant to spur pro-environmental behaviour [251] and to support information as structural strategies. Requisites of the "environmental-human/tech" communication relationship would thereby englobe the aforementioned *product* and *producers'* dimensions. In this line, our conceptual design envisions interpretation and performance functionalities, which addresses respectively environmental information and education as also action coaching. Taken together, we believe that these features assist individuals to enhance self-efficacy perception and hopefully maintain positive outcome expectations aligned with pro-environmental behaviour.

4. *Earthsensum* design study

The practical design work discussed in this section focuses on the concept experience consisting of the chemical sense experience and the digital media experience. Insofar we aimed to address environmental health communication, prior to the study experiment we attempted to know more about our participants mindset regarding their environmental beliefs and attitudes. This approach would help us to have some insight about what behaviour is already established, and what expectations are not met.

4.1. Set up and participants

The experiments were conducted at the "Aromni" equipped Showroom, located at FCT NOVA - (Faculty of Science and Technology - New University of Lisbon) at the time of this study. The study was approved by the FCT Nova Ethics Committee at the NOVA University of Lisbon.

Participants agreed about the outline and procedure of the complete test setting. We asked permission to audio and video recording, as also taking photos. All volunteers read and signed informed consent before participating, not receiving any compensation.

4.1.1. Participants demographics

In total, 16 participants (Females = 2) between the ages 17 and 64 years (M = 18.5 years, SD = 13.46) volunteered to take part in the study, all based in Portugal (Figure 15 - left). They were recruited on an opportunity-sampling basis. The education level of participants ranged from undergraduate (n= 11), bachelor (n=3) and doctoral degree (n=2). The average expertise area covered "Technology and

Informatics” (n= 13), complemented with “Augmented Reality” (n= 1), “Chemistry” (n= 1), and “Research and Development” (n= 1).

4.2. Participants environmental attitudes

To gain insight about participants environmental mind set, we inquired about a set of their environmental attitudes: Environmental awareness self-evaluation, information habits and behaviour outcome expectation.

4.2.1. Methodology

Prior to the sensorial and digital media prototype testing, we provided computer-based surveys and conducted interviews for qualitative and quantitative analyses.

4.2.1.1. Environmental Awareness Self-Evaluation

Procedure.

Participants were instructed to self-evaluate their environmental awareness *"Do you consider yourself environmentally conscious? (1= "Strongly Disagree"; 5= "Strongly Agree"*)" using a button-box. Following, we asked the open-ended question *“How does it influence your daily life?”*, to inquire how the previous statement was reflected in every-day life.

Results.

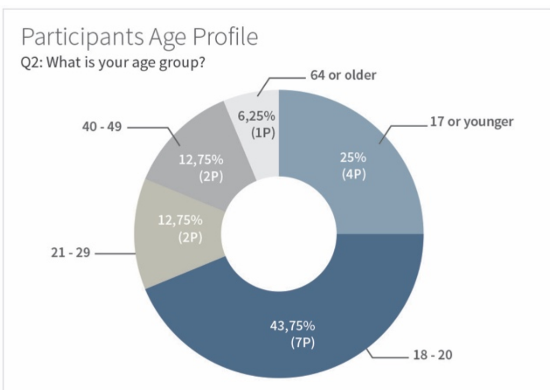
Out of total 16 participants, 81,25% (n=13) stated they are environmentally conscious (Figure 15 - right). When asked about how their environmental consciousness influenced their daily life, we found self-regulatory statements reflecting moral norms: *"I have strong values and they guide me throughout my choices."* (P6); the influence of past behaviour: *"I'm more careful about everything I do."* (P7) and action determination: *"Yes, in eco-friendly behaviours."*(P14). 31,25% identified specific actions such as recycling (n=2), sustainable mobility (n=2) and consumption reduction (n=1).

"On recycling and reusing as much as possible."(P5);

"I use public transport, by preference. In this manner, there are fewer cars, less confusion, less pollution."(P13);

"I try to diminish the consume of general products, including food and consumer products." (P16).

Additionally, P3 pointed on deciding *"The way I dress"*, as influence consequence.



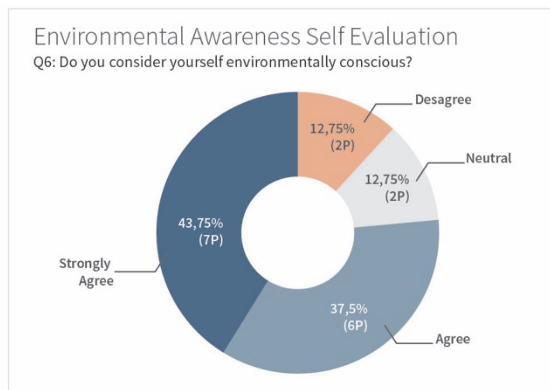


Figure 15 - Participants age group distribution (left) and environmental awareness self-evaluation (right).

4.2.1.2. Environmental Information habits

Procedure.

The survey proceeded asking participants about their environmental information habits in terms of its frequency, satisfaction and impact. Questions included *"Do you access environmental information? ("Daily''; "Weekly''; "Monthly''; "Sometimes")"* and *"Are you satisfied with the* *information you get? ("Yes"; "No"; "Sometimes")"* using button options. Additionally, we provided a text field for open responses asking *"Does the information content influence your behaviour?"*.

Results.

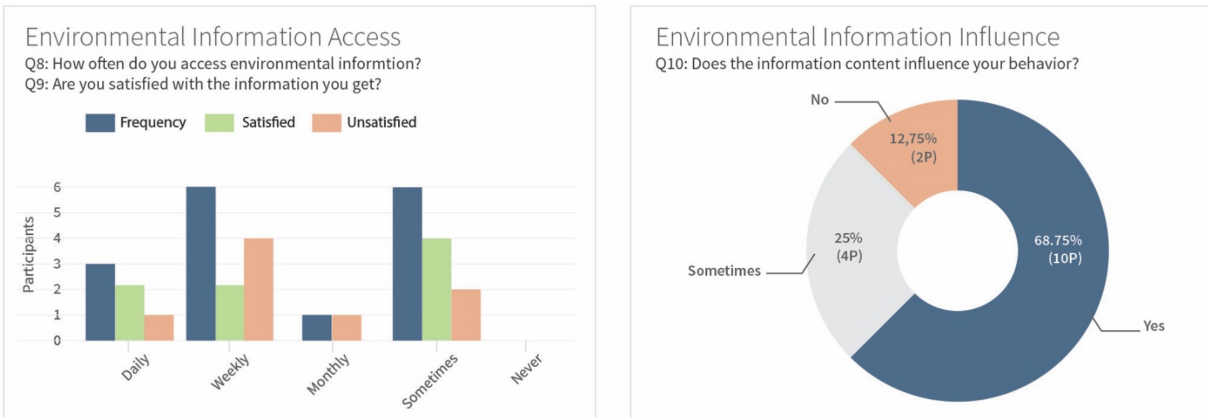


Figure 16 - Participants environmental information access in terms of frequency and satisfaction (left) and environmental Information influence on participants behaviour (right).

- **Information access**

Out of total 16 participants, the average access environmental information on a *"Weekly''* basis (n=6) or *"Sometimes"*(n=6) (Figure 16 – left).

- **Information delivery satisfaction**

Satisfaction ratings by these two groups exhibited divergences (Figure 16 – right). For the ones who access *"Weekly"*, the most were not satisfied (n=4) with the environmental information delivery. Inversely, the group who access *"Sometimes"*, were satisfied (n=4).

- **Information influence on behaviour**

Most of the participants (62,50%) stated that information delivery influenced always their behaviour. We identified as influence factors motivation; engagement; reliability and normative beliefs.

Motivation.

Four participants (25%) argued that motivation factors influenced their behaviour in terms of education, safety and adaptation.

"I'm curious about what is happening in the world and about climate change" (P3).

"Yes. So, I can think of ways to use it" *(P7).*

"When I researched for a homework assignment about toxic gases, it made me think about how to manage the fireplace at my home. Since then, at bedtime, I always make sure that the fire is properly extinguished" *(P8).*

"Yes, before leaving the house, to know the weather. This influences on what I dress" *(P9).*

Engagement.

One participant (6,25%) stated that visual engagement influences his behaviour:

"Through the images. The visual impact of the images that show environmental problems, like pollution in China, pollution of the Seas, makes me think about what I can do to reduce pollution." (P13).

Reliability.

Moreover, four participants (25%) showed reserved adherence to content information.

"It depends on the type of information. It influences me accordingly" *(P4).*

Personal normative beliefs.

Finally, two participants (12,5%) mentioned personal values, beliefs and norms guiding their willingness to perform pro-environmental behaviour.

"In my perspective, I do the duty of any human being" *(P15).*

"I have been recycling since I'm 13. So, the information I get today is not what influences me. It was a close relative who influenced and educated me. Nevertheless, the contents of the programs or articles that I consult inspires me to take more attention to other subjects and motivate to do something more for the environment" *(P10).*

4.2.1.3. Behaviour outcome expectation

Procedure.

Participants were asked about what impact expectation they believed their behaviour had on the environment. We analysed the qualitative data in terms of individual's low, neutral or high efficacy beliefs on their behaviour outcome expectations.

Results.

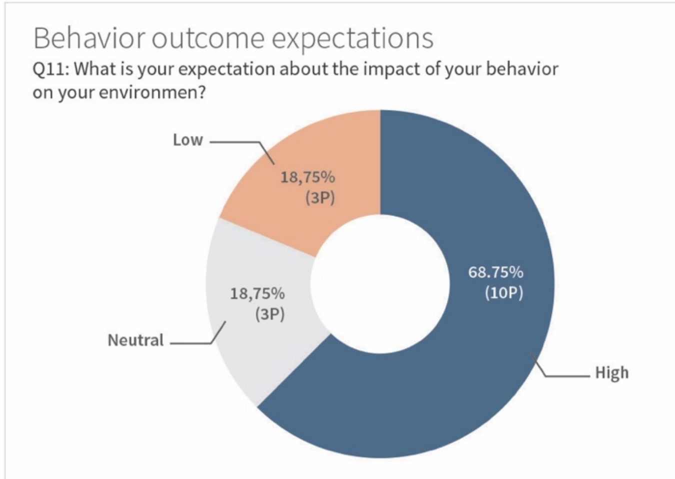


Figure 17 - Participants behaviour outcome expectation.

Out of total 16 participants, 62,50% (n=10) formed a high outcome expectations group (

Figure 17). They revealed installed behaviour habits for individual or collective benefits such as recycling and sustainable mobility or health and normative beliefs. Herein we present a selection of quotes:

"(..) I recycle every single thing that I use" *(P7).*

"If all people walk by foot instead of by car, the air would get less polluted. In other words, more people should walk more" *(P9).*

"Protecting my health" *(P8).*

"Set an example and show an attitude" *(P10).*

"If I, or other people like me, take action to reduce pollution, it helps everyone" *(P13).*

The neutral group - 18.75% (n=3) - showed reduced perceived self and collective efficacy, such as:

"Continue the same"*(P11).*

"I try not to pollute the planet as much as possible. But just because I am not polluting the planet, I think it will not make much difference in the world" *(P3).*

The low outcome expectations group - 18.75% (n=3) - presented distrust in self and collective efficacy:

"I'm afraid none" *(P6).*

"My behaviour is well eco-adapted. The common people are not who make the impact. We (people) are not the main source of the problem. It is the behaviour of companies and industry that is the main problem. They bypass the law and pollute rivers with industrial discharges, among other offensive actions" *(P2).*

Concluding, participants profile sample let us conclude having a high environmental consciousness and installed pro-environmental behaviours. Furthermore, they have high outcome expectations about their behaviour on the environment. Effectively they are concerned about adapting needs to incremental environmental changes due to ethic as also hedonic reasons. Their environmental information requirements are covered on a "*Weekly*" basis or eventually "*Sometime*s". The average stated that content interaction influenced always their behaviour, despite information delivery is not always satisfactory.

The Concept Experience

The concept experience comprises the Chemical Sense experience and the Digital Media experience, refereeing respectively to crossmodal association and prototype interaction. The interactive demos were designed considering Mobile Virtual Reality (MVR) and Mobile Augmented Reality (MAR) technology. Appendix A1 and Appendix A2 present the online questionnaires.

5. Design phase 1: The chemical sense experience

In this section of our study, we explore cross-sensory analogies and symbolic construction layer of our Multisensory HCI design process. It encompasses defining an “environmental chemical senses correspondence chart”, selecting and producing stimuli samples and providing association attribution options.

5.1. Stimuli selection.

We selected smell and taste samples based on its representativeness of environmental issues. Information about environmental health [252], world trade [253] and pro-environmental strategies, [254], [255], lead as to synthesize the interconnection of a specific geographic location with its ruling industries and cultural practices.

Accordingly, we targeted solid waste and pulp industry as also the seacoast in the Portuguese territory. Whereas, globally we targeted plastic, meat and garment overconsumption linked with geographic location presenting high air pollution indexes at the time of this study.

Next, we defined an “environmental chemical sense correspondences chart” organized by stimuli; molecule highlight, location, geo coordinates, sample source and call for action themes (see Table 1).

This categorization provided basic guidelines for content development throughout *Earthsensum's* design process.

Table 1 - Chemical Sense correspondences chart for sample and content development.

Sample	Stimuli	Molecule highlight	Location	GPS	Sample Source	Call for action themes
Smell A	Solid waste	Ammonia	Waste treatment Station, Portugal	38.744959, -9.326482	Household Ammonia	Waste prevention and recycling
Smell B	Cellulose	Hydrogen Sulfide	Pulp industry, Portugal	40.053199, -8.865728	Rotten Eggs	Paper waste reduction
Smell C	Sea	Dimethyl Sulfide	Seacoast, Portugal	38.804254, -9.484806	Seaweed	Plastic waste reduction; Sustainable fish and seafood consumption
Taste A	Spinach	Chlorophyll	Tehran, Iran	35.664816, 51.359608	Spinach Leaves	Car use reduction; Plastic waste reduction
Taste B	Soybean	Water	Beijing, China	39.907256, 116.375481	Soy Sauce	Discarded electronics reduction; Meat consumption reduction
Taste C	Clove	Eugenol	Dhaka, Bangladesh	23.811389, 90.421289	Biryani Spice	Clothing waste reduction

In these lines, smell experiences include Ammonia addressing the solid waste industry; Hydrogen sulfide referring cellulose industry and Dimethyl sulfide alluding the seacoast industry. With regards to taste, it is the principal ingredient source who acts as the representative agent. They cover Spinach refereeing to the city of Tehran (Iran); Soybean to Beijing (China) and Clove to Dhaka (Bangladesh). These options are related to the cities with high air pollution indices, at the time of our study. Whereas, the ingredients belong to the local cultural gastronomy and available in the global western market.

5.2. Stimuli production

Smell. We prepared the ammonia sample by diluting common household ammonia solution and water with a dilution 1/100. The hydrogen sulfide sample resulted from natural seven-day decomposition process of one fresh egg yolk left in an unclosed recipient. Finally, the dimethyl sulfide sample resulted from immersing dry wakame algae in one water glass of seawater for seven days.

Taste. The chlorophyll experience was offered by steamed fresh spinach leaves. For the soybean and the clove's eugenol experience, we opted to use cooked white rice as a base and seasoning separately with the respective ingredients. That is, with Shoyu Soy Sauce by *Clearspring* and Bombay Biryani Mix by *Shan*.

5.3. Procedure and Method

Our experiment adopted a within-group method design. Eight participants were assigned for the smell experience group and eight participants for the taste experience group. After participants aforementioned agreement protocol and explanation of the proceedings, they were guided to the test setup. Smell and taste experiments were performed at different times schedules.

5.3.1. Stimuli presentation

Smell. The smell sample presentation followed previous studies procedure in the fields of experimental psychology [58]. We displayed three jars on a table, swathed with tape paper to avoid visual cues of

its content. Participants handled them manually and were instructed to hold each jar 20 cm away from their nose while sniffing.
We suggested the smelling order by increasing arousal properties (from low to high).

Taste. The taste sample presentation was inspired by a previous crossmodal study [226]. Small amounts of food were served on ceramic spoons displayed on a table. Participants handled the ceramic spoons manually. We recommended taking small bites by taste arousal intensity order (from low to high).

5.3.2. Association tasks

After completing of the smelling or tasting, we asked participants to translate their perceptions by associating semantic, haptic, graphic and affective attributes.

5.3.2.1. Semantic Association

Olfactory and gustatory language is predominantly shaped by cultural factors and available vocabulary [233], [256], [257]. Hence, we wanted to investigate participants preferences to describe chemical sense experiences. To this end, we applied two methods: (1) choosing words from a predefined list and (2) description with our own vocabulary. For the first method, we compiled a list of smell and taste descriptors organized by source, category and affect (see Table 2), based on different sources of classification systems [108], [230], [258]. Immediately after stimuli experience, participants were asked to choose any words from the list which best matched their stimuli perception for quantitative analyses (Appendix A3 and Appendix A4). The second method was performed after this section of the study.
We asked participants to recall what they perceived and express with

their own words, for qualitative analyses. At this stage, we also inquired about method description preference.

Table 2 - List of Semantic descriptors for smell and taste experiences.

	Smell descriptors	**Taste descriptors**
Source	animals, cleaning, coffee, complex, construction, emissions, food / beverage, humans, industrial, nature, non-food, smoke, subway, synthetic fragrance, tobacco, waste	dairy products, fruits, leaves, legume, meat, poultry, root, seafood, seeds, spice, whole grain
Category	acid, ammonia / ruinous, bakery, burnt, chemical, cold, decayed, fish, flower, fruit, garlic, grass, musky, sour, spices, sweaty, sweet, warm, wood	bitter, bland, crunchy, dry, greasy, moist, piping hot, rich, salty, savoury, scrumptious, sour, spicy, sugary, sweet, tasty
Affect	agreeable, aromatic, bad, characteristic, delicate, delicious, delightful, disgusting, distinct, evil, exquisite, faint, fresh, grateful, heavy nasty, nauseous, offensive, peculiar, penetrating, pleasant, powerful, pungent, rich, sickening, strange, strong, suffocating, unpleasant	amazing, appealing, appetizing, delectable, delicious, delightful, disgusting, divine, enjoyable, enticing, excellent, exquisite, extraordinary, fantastic, finger, heavenly, licking, lip smacking, luscious, marvellous, mouth-watering, palatable, pleasant, pleasing, satisfying, scrumptious, strange, superb, tantalizing, tasty, terrific, unpleasant, wonderful, yummy

5.3.2.2. Haptic association

Volumetric objects and materials were ordered randomly on a tray. Object options covered round, point edged and angular shapes in the form of a tennis ball, trigger ball and cube. Material options comprised rough, regular and soft textures by making use of sandpaper, denim and velvet. Participants were asked to choose one shape and one texture option for each *stimuli* experience for quantitative analyses (Figure 18 - right).

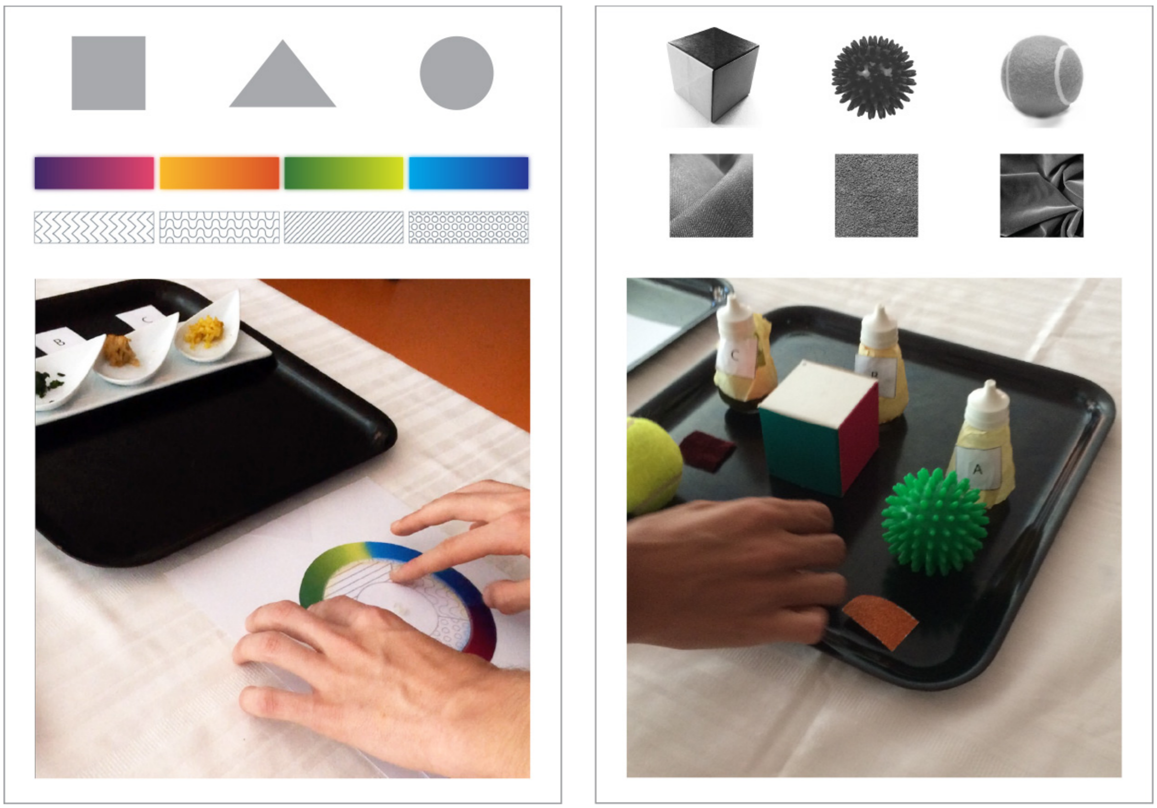


Figure 18 - Association tasks: Graphic components attribution by shape, colour and textures handling the interface prototype (left). Haptic associations with objects and textures (right).

5.3.2.3. Graphic component association

We ideated an interface design and build a paper prototype [46] which featured graphic shape, colour and texture selection options (Figure 18 - left). In accordance, we provided triangle, square, circle options;

purple, orange green; and blue colour options. While texture options comprise zigzag, diagonals, waves and circles. The interface concept purposes the user sliding the inner and outer circle around a centre axis, until final selection alignment (Figure 19).

Figure 19 - Interface concept and paper prototype handling

5.3.2.4. Affective association

Sensorial experiences are mediated by emotional responses. In this line, we measured psychometric variables with Bradley's Self-Assessment Manikin (SAM) scale [259]. We asked participants to fill out online Self-Assessment questionnaire answering questions about Pleasantness - *"Did you like the smell/taste?* (1= *"Strongly Disagree"*; 5= *"Strongly Agree")"*; Valence - *"How does this smell/ taste make you feel?* (1= *"Sad"*; 5= *"Happy")"* and Arousal - *"What impact has this smell/taste on you?* (1= *"Calm"*; 5= *"Excited"*)". Association

5.3.3. Association tasks results

In this section we present the findings according to the four association dimensions.

5.3.3.1. Semantic Association

The first method applies quantitative analysis focused on the word association task. Figure 20 presents the most frequently selected words for each chemical sense experience. Figure 23 provides a summary of these words. The size of the words depends on their frequency of use, with larger words being more frequent than smaller words.

Smell. Words like "strong", "chemical" and "powerful" were more often selected when describing the ammonia smell experience. Whereas the most words associated with hydrogen supplied were "burnt", "decayed", "fish", "fruit", "sour" and "sickening", among others. Finally, "grass", "food", "nature", "wood", "agreeable" and "aromatic" were dimethyl sulfide word choices.

Taste. Regarding the taste experience, spinach most associated words were "enjoyable", "leaves ", "legume" and "moist". The soy experience comprised "seafood", "seeds" and "spice". At last, the clove experience most frequent word choices were "spice", "moist" and "piping hot".

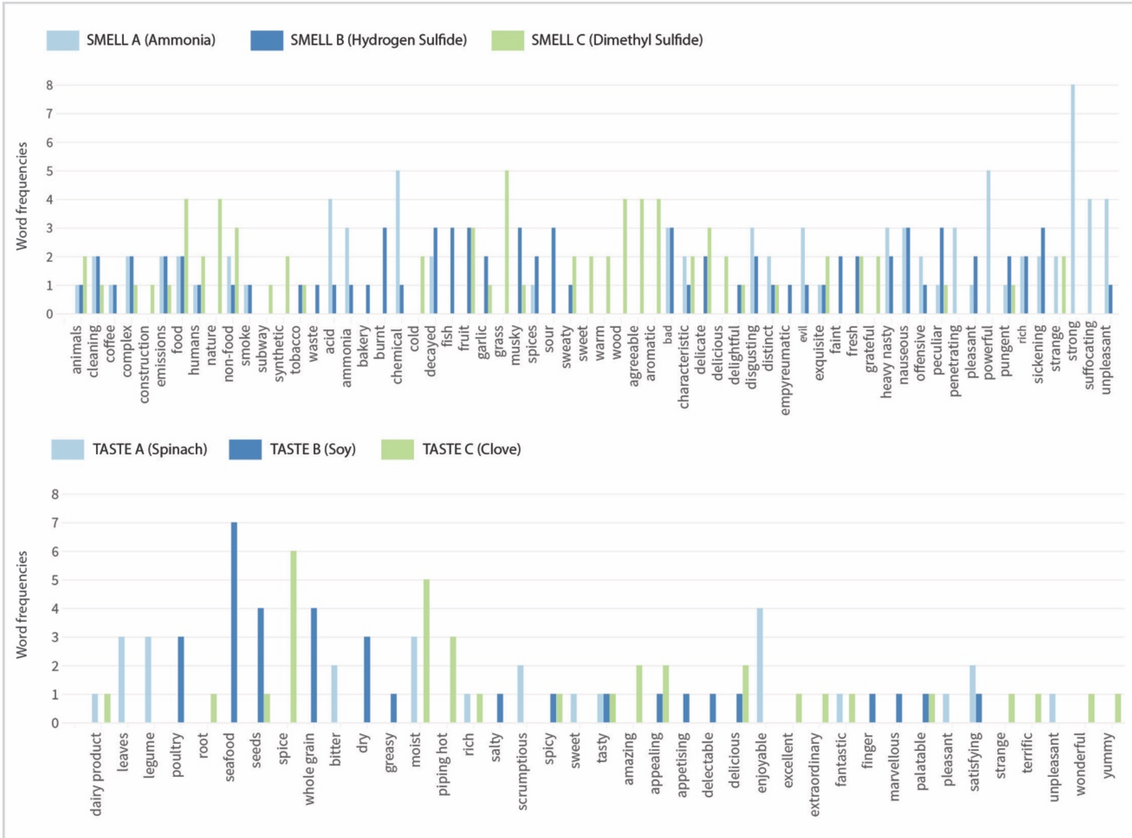


Figure 20 - The most frequently selected words for smell (upper row) and taste (lower row).

The second method applies qualitative analysis to determine participants personal translation strategies of these experiences. Two main themes emerged: functional and representative. The functional theme contains essential descriptive word choices. The representative theme refers to the use of metaphors. We present herein representative quotes for each smell and taste perception (Table 3).

Table 3 - Personal verbal descriptions of smell and taste perceptions.

Stimuli	Sample	Functional	Representative
Smell	Ammonia	"Burning" (P3); "Horrible" (P8)	"Disgusting, urge to escape, a terror movie" (P5); "It is an acid smell which I can't identify (P6)
	Hydrogen sulfide	"Disgust" (P1); "Industrial" (P2)	"A day of autumn" (P4); "Intensely unpleasant, but bearable at the limit" (P5)
	Dimethyl sulfide	"Neutral" (P3); "Strange" (P8)	"A calm smell that does not attract much attention" (P6); "It is a soft and characteristic smell" (P7).
Taste	Spinach	"Spinach" (P10); "Unpleasant" (P13)	"Feels like a connection with pure nature" (P14); "Field" (P16)
	Soy	"Strange" (P12); "Neutral" (P15)	"It seemed to me something like "Bacalhau à Brás"[10] (P11); "Rice fields, rivers and birds" (P16)
	Clove	"Awkward" (P12); "Spicy" (P13)	"Experience - excited my gut" (P14); "Above the real world, sublime" (P16).

Out of total 16 participants, the elected description method is from a predefined list (56,25%). Pointed reasons were convenience and speed. Selecting words from a list helps to overcome lack of vocabulary and it is perceived as a faster method than using personal vocabulary.

[10] "Bacalhau à Brás" is a portuguese traditional dish made with salted cod (Bacalhau), onions, potatoes and scrambled eggs.

5.3.3.2. Haptic Association

Quantitative data results let us conclude that volumetric shapes and texture material compilations allowed translation of human subjective experiences. They validated singular and collective profiles of sensorial perceptions.

Smell. Collectively, ammonia was mapped as a point edged object (n=6). with a rough texture (n=6). Hydrogen sulfide was synthesized as an angular object (n=6) and a regular texture (n=6). Finally, dimethyl sulfide was translated as a round object (n=5) with a soft texture (n=8).

Taste. Regarding haptic taste association, spinach was represented by a round object (n=5) and regular texture (n=5); Soy an angular object (n=4) and soft texture (n=4); Clove as a point edged object (n=7) and rough texture (n=7). Figure 21 presents individual association data of smell perception and Figure 22 for taste perception. Figure 23 shows the collective profile of these smell and taste perceptions. Appendix B1 - Table 10 presents the quantitative analyses of haptic components attribution.

Complementary Information:
A selection of haptic associations is accessible online with a password:

- Haptic-Taste-1A: https://vimeo.com/351657507
  password = earthsensum-haptic-T1A

- Haptic-Taste-5B: https://vimeo.com/351664640
  password = earthsensum-haptic-T5B

- Haptic-Taste-8B: https://vimeo.com/351664986
  password = earthsensum-haptic-T8B

5.3.3.3. Graphic Association

Results of quantitative analysis showed that abstract graphic forms enabled subjects to communicate smell and taste. From anecdotal observations that should be properly followed up, we found that participants reached independently similar symbolic formulations to represent sensorial experiences. Data clusters also showed a collective map of symbolic representation of these sensorial experiences.

Smell. Collectively, ammonia was interpreted was purple (n=4), zigzag texture (n=5), triangle shape (n=6). Hydrogen sulfide was purple (n=3), wave texture (n=5), square shape (n=7). Dimethyl sulfide was blue (n=5), circle texture (n=5), circle shape (n=6).

Taste. The collective Spinach representation was the colour green (n=5), diagonal texture (n=7), triangle shape (n=3) and circle shape (n=3). Soy was blue (n=4), circle texture (n=4), square shape (n=5). Clove was orange (n=6), zigzag texture by (n=6), triangle shape (n=4).

Appendix B1 - Table 11 presents quantitative analyses of graphic components attribution. See Figure 21 for individual association data of smell perception and Figure 22 for taste perception. Figure 23 shows the collective profile of these smell and taste perceptions.

Complementary information:
A selection of graphic associations is accessible online with a password:

- Graphic-Interface-T1B: https://vimeo.com/361532334
  password = earthsensum-graphic-T1B

- Graphic-Interface-T6B: https://vimeo.com/351655036
  password = earthsensum-graphic-T6B

- Graphic-Interface-S8B: https://vimeo.com/351373321
  password = earthsensum-graphic-S8B

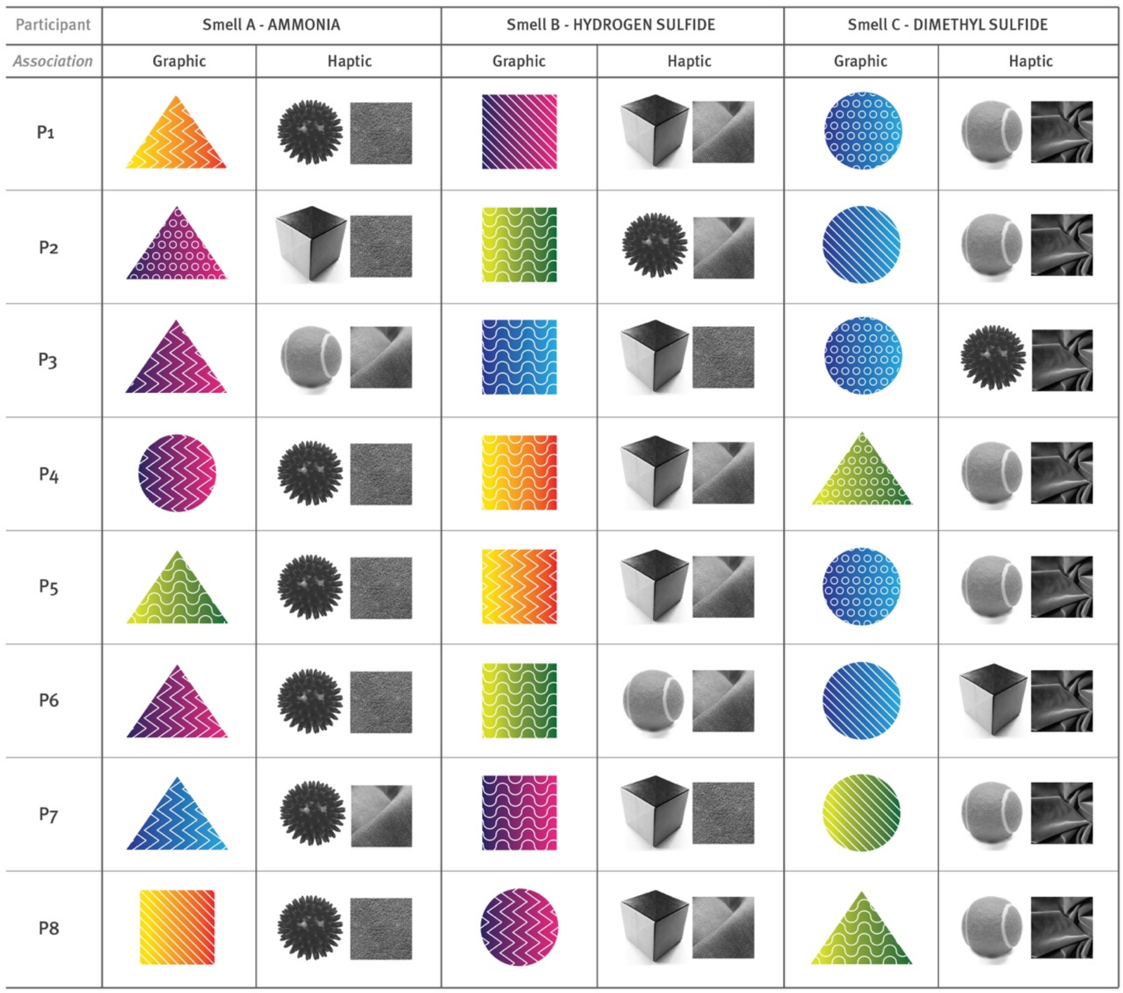


Figure 21 - The individual symbolic representation profile of smell perceptions by graphic and haptic components association (P1-P8)

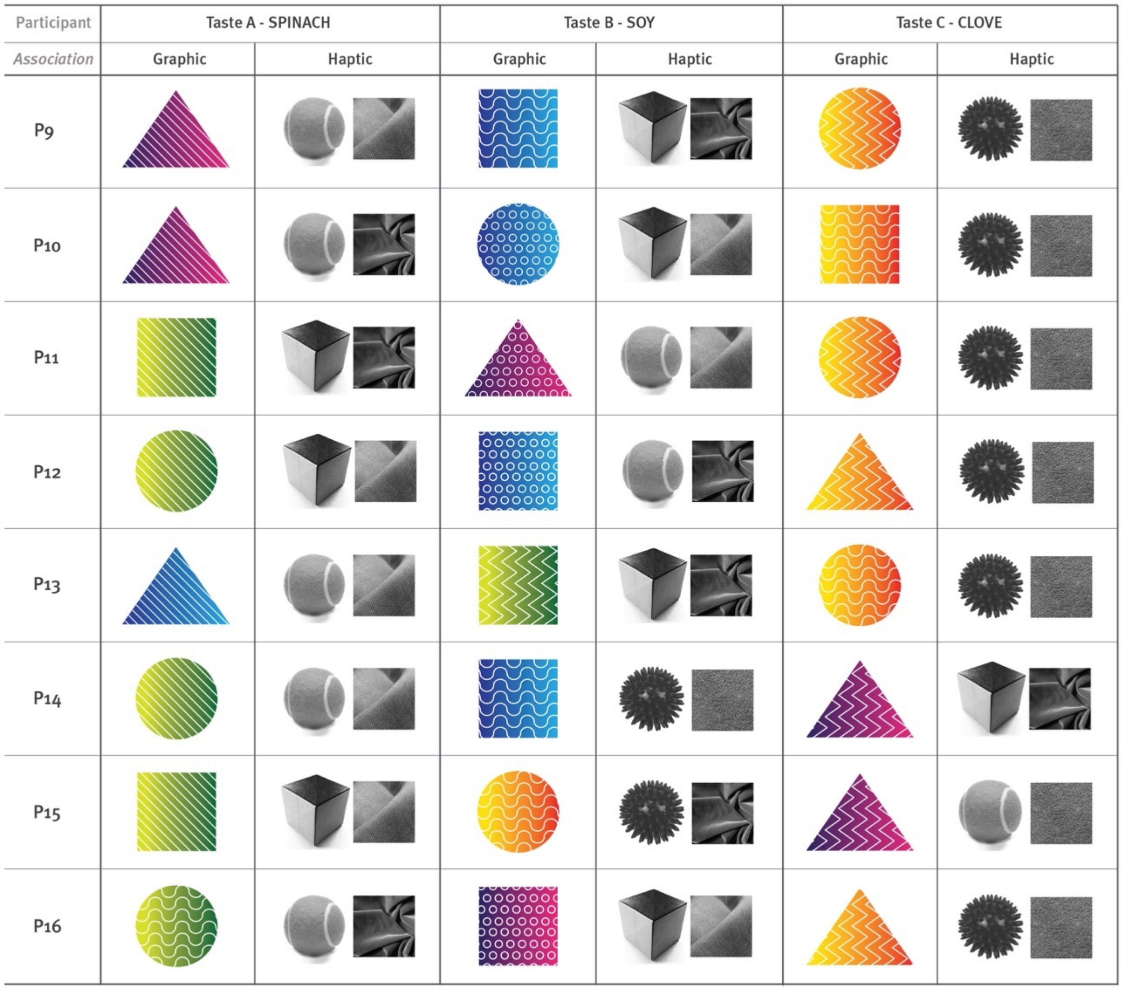


Figure 22 - The individual symbolic representation profile of taste perceptions by graphic and haptic components association (P9-P16)

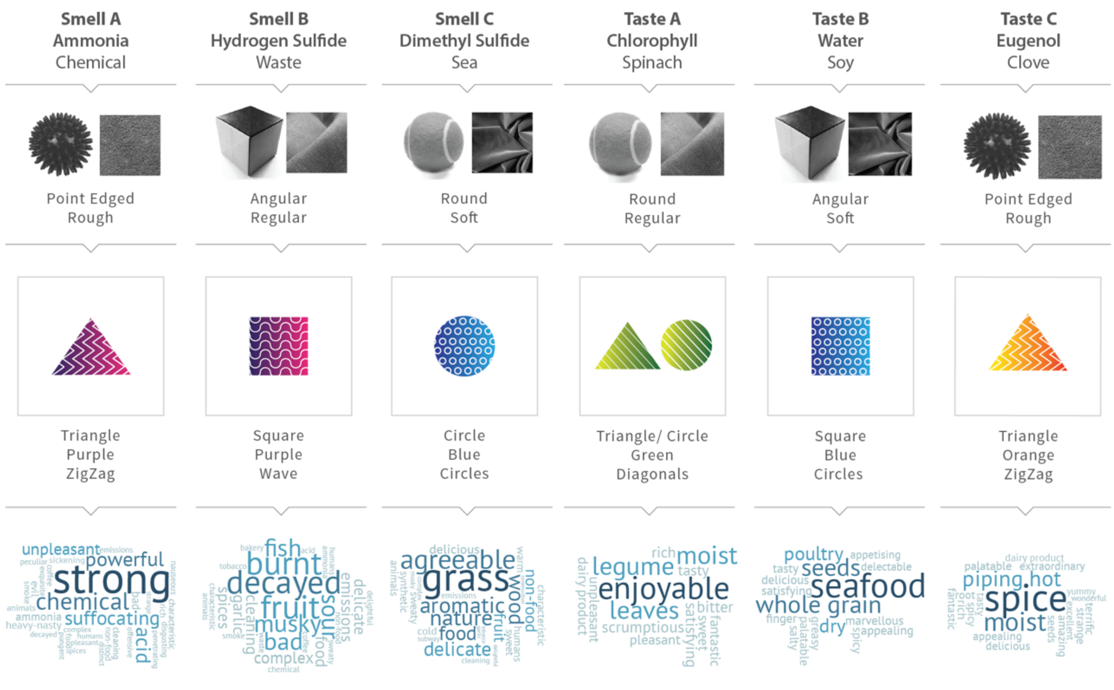


Figure 23 - The collective profile of smell and taste perceptions by haptic (first row), graphic (second row) and semantic (third row) associations.

5.3.3.4. Affective Association

We performed quantitative analyses pleasantness, valence and arousal response (Figure 24).

Smell. Data revealed that Ammonia was “strongly unpleasant” (n=6), evoked feelings of “unsatisfied” (n=4), and had an "excited” (n=3) arousal effect on participants. Hydrogen sulfide was "unpleasant" (6P), evoked feelings of “unsatisfied” (n=5) and arousal effect was “dull” (n=5). Whereas, dimethyl sulfide was rated as "neutral" either for pleasantness (n=5), valence (n=4) and arousal (n=6) dimension.

Taste. Spinach was "pleasant" (n=5), its valence “neutral” (n=4), with a “calm” (n=5) impact. Soy was perceived as "neutral" for pleasantness (n=5), valence (n=4) and arousal (n=5) dimensions. Clove instead was ranked as "pleasant” (n=5), evoking "happy” feelings (n=4) with arousal dimension of “excited” (n=3) and “dull” (n=3).

Figure 24 - Results of participants affective evaluation of smell and taste perceptions for pleasantness, valence and arousal dimensions.

5.3.3.5. Summary of design phase 1

In this section of our study, we explored cross-sensory analogies and symbolic construction possibilities of semantic, haptic, graphic and affective association with smell and taste experiences. Association features allowed individuals to describe smell and taste perceptions. Additionally, data collection sets enable individual and collective profiling of these experiences (Appendix B2 - Figure 41 and B3 - Figure 42). Adaptation of these association features on interface modules enables symbolic displaying of chemical sense experiences. This first design phase provided smell and taste experiences without contextual clues. The second design phase provides the contextualization of these experiences applying digital media experiences.

6. Design phase 2: Digital media experience

In this section of the study, we explore the meaning and communication construction layer of our Mutisensory HCI design process. We present the conceptualization, design and implementation of digital media experiences, following our design hypothesis formulations. To this end, we conceived and designed digital product concepts considering Mobile Virtual Reality (MVR) and Mobile Augmented Reality (MAR) technology. In accordance, we build prototypes for User Experience (UX) evaluation.

6.1. Design hypothesis 1**:** *Earthsensum* design case with virtual reality technology

Based on the design hypothesis 1 formulation, we ideated a Virtual Reality (VR) experience concept. Our design process covered user flow analyses, information architecture diagram, storyboard for content flow planning and asset production. The company Aromni provided one senior developer for a limited time span, to implement the experience on Unity 3D platform. The final prototype demo reflects these technical considerations.

6.1.1. VR general design guidelines

In general VR applications encompass two main components: environments and interfaces. The environment is the world that we enter when we put on a VR headset - the virtual world. An interface is the set of elements that users interact with to navigate an environment and control their experience. VR design frameworks and guidelines are not easy to define. Sutcliffe states that "(…) VR interaction design methods have tended to concentrate on design for generic actions, navigation, selection, and manipulation with little advice on trade-offs related to the user's task, e.g., design for usability and efficient operations versus realism and immersive experience. While cognitive issues pertinent to immersion, presence, and embodiment have been extensively researched in VR, advice on inter-action design has received less attention" [260, p. 10]. The challenge of VR interaction design is balancing contextual sensitive design decisions with the expressive power of these actions and the user's task completion needs.

6.1.1.1. VR user experience guidelines

The main design principles for optimized VR User experience [261]–[263] has to take into account characteristics of current Head-Mounted Displays (HMD). Virtual Reality is a physical experience involving the viewer's head, neck, and eye muscles to rotate the head around and focus on objects at different depths. These interacting modes entails human ergonomic characteristics. Albers [264] proposes main zones for design intervention, based on Chu [265] and Alger's [266] findings.

Physiological Comfort - In virtual environments symptoms of nausea, claustrophobia, and similar may happen. It is recommended to provide a fixed reference point to reduce motion sickness.

Environmental Comfort – The viewer has to feel comfortable and secure in virtual environments. Elements of scale should be placed in the virtual space as a scale reference. Non-spatial elements of light and sound also assist the viewer to locate himself in the virtual space.

Input Methods - In general Mobile VR headsets kit provide three degrees of freedom (3DoF)[11] controllers and act as a pointer. More

[11] Degrees of freedom refer to the number of basic ways a rigid object can move through three-dimensional space. Three degrees of freedom (3DOF) moves 3 axis which are roll (longitudinal axis), yaw

advanced equipment with six degrees of freedom (6DoF)[12] controllers add the ability to reach out and interact with objects in a three-dimensional space. Moreover, sensor-based wearables like gloves and optical systems add even more complexity and enhances the perception of full immersion [261].

Sound – Acoustics favours immersion feature. Stereophonic sound provides sound coming from two channels (left/right). However, holophonic sound allows us to merge with the virtual reality experience It stimulates three-dimensional sounds enabling spatial perception and immersion.

6.1.1.2. VR user interface guidelines

- **Setting Up the Scene: Human Ergonomics.**

Virtual Reality is a physical experience involving the viewer's head, neck, and eye muscles to rotate their head around and focus on objects at different depths. These interacting modes entail human ergonomic characteristics when designing for current Head-Mounted Displays (HMD). Thus, considerations about the range of motion, content placement zones and placement are key for strategic interaction design.

(normal axis), and pitch (transverse axis). Source: https://developers.google.com/vr/discover/degrees-of-freedom . Accessed: 12.11.2020

[12] Six degrees of freedom (6DoF) moves 6 axis which are forward/backward (surge), up/down (heave), left/right (sway) translation in three perpendicular axes, combined with changes in orientation through rotation about three perpendicular axes, often termed yaw (normal axis), pitch (transverse axis), and roll (longitudinal axis). Source: https://en.wikipedia.org/wiki/Six_degrees_of_freedom. Accessed: 12.11.2020

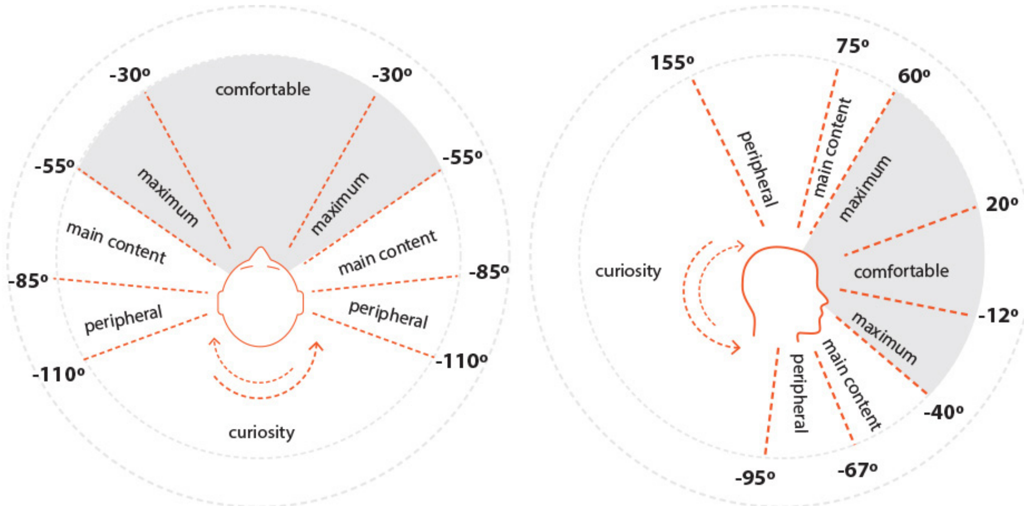


Figure 25 - VR Design Ergonomic Facts: Comfortable and Maximum Range of Motion

- **Comfortable and Maximum Range of Motion.**

The comfortable viewable range is ±30° horizontally, +20° up, and -12° down. The maximum viewable range is ±55° horizontally, +60° up, and -40° down [265] (Figure 25).

- **Main content, Peripheral and Curiosity Zone**
  Spatial content placement influence interaction strategies as also content exploration [264]–[266]:
  - The main content zone: Content is easily accessible to the viewer.
  - The peripheral zone: The viewer has to strain to see the content.
  - The curiosity zone: The viewer has to rotate their body.

Considering a standard 110° field of view, the main content zone is 85° to each side - 75° up, and 67° down [267]. The peripheral zone extends 110° to each side and past 90° both up and down. Content beyond 110° to each side and behind viewers addresses the curiosity zone.

- **Content Placement**
  Albers [264] recommends a permanent content zone of 2,5m - 4m distance away from the viewer at 15°-50° [264]. In addition, Chu

[265] advocates a “Main UI Zone” located at a “comfortable depth” with “good stereoscopic effect” while minimizing eye strain over a long period of time. Chu’s Main UI Zone is the union of the X/Y Main UI Zone” (±30° in X & +20°/-12° in Y) and the edge of the “Strong 3D”/”Some 3D zone” (8m - 12m in Z) (Figure 26).

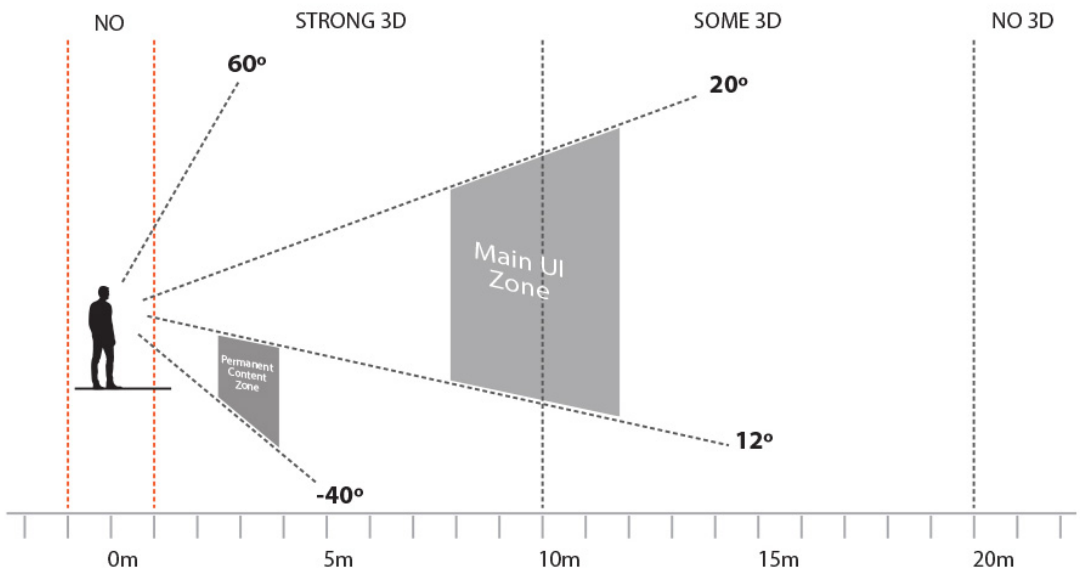


Figure 26 - VR Design Ergonomic Facts: Zones of content placement

- **Setting Up the View: Canvas Size.**

Virtual environments replicate the real world and consequently do not have visual limitation references. Designing user experiences for VR apps infer to define a functional canvas size to present the interface components. When flattening a 360-degree environment, the result is an equirectangular projection. This map projection is a cylindrical equidistant projection, also called a rectangular projection. In three-dimensional environments, equirectangular projections are wrapped around a sphere to mimic the real world.

The full width of the projection represents 360 degrees horizontally and 180 degrees vertically. Therefore, rectangular grid calculations have been used to define the total pixel size of the"360 View" canvas: 3600 × 1800 pixels. Considering the whole panorama grid, UX and UI design contents only focus on a small portion of the total space available. In relation to the equirectangular, its position is centre orientated with 1200 × 600 pixels in size [268] (Figure 27).

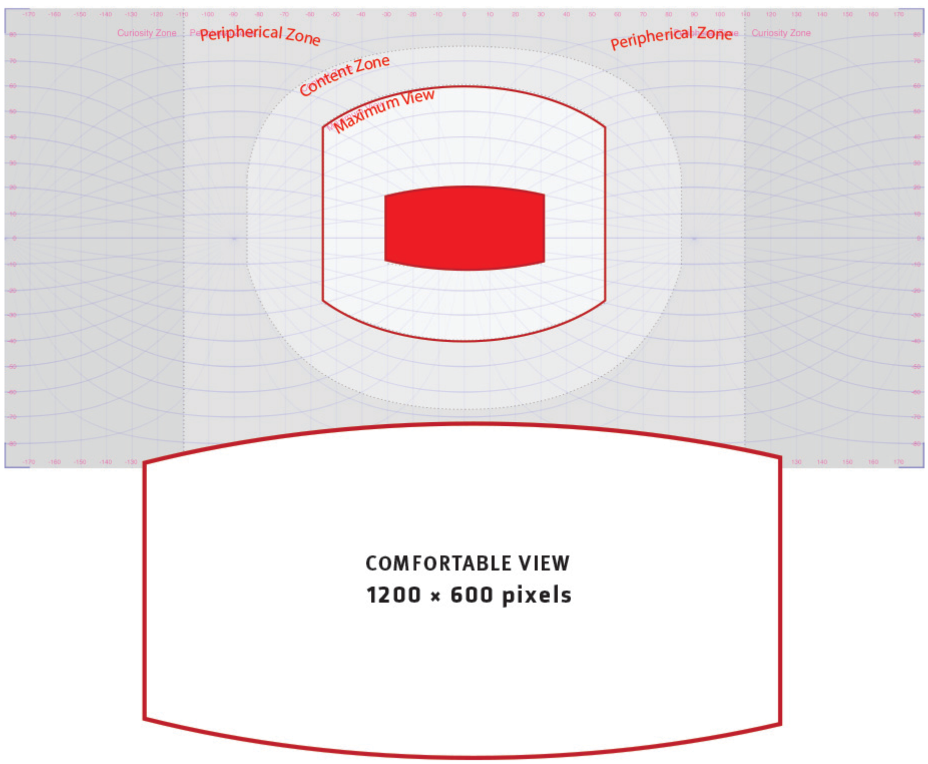


Figure 27 - Panorama Grid and Comfortable View Canvas Size.

Common recommendation contemplates avoiding big text blocks and detailed typographic families. Whereas, interactive targets, such as buttons, should be large and sufficiently far apart from each other. Nevertheless, setting optimal typography readability and interaction components requires experimentation and testing thought the design process.

6.1.2. Design development

In accordance with the hypothesis 1 formulation, we conceptualized an immersive experience that targets the non-scientific public and considered the following features:

- Assessing a holistic perspective of environmental events and impacts.

- Sensitising about environmental impacts on people and cultures of these localities.

- Deliver environmental health education information.

- Motivating pro-environmental behaviour.

Earthsensum VR design process encompasses information architecture, storyboard; content and media development; Low-Fi Wireframing and Hi-Fi prototype implementation.

6.1.2.1. Concept

Our VR design approach aimed to explore immersion and transferability attributes but keeping interaction features simple. Essentially, we expected the viewer to be transferred to the "local scene" and empathize with what is happening" over there". As such, interaction requirements implied to move through the scenes. For doing so, we decided to implement eye gaze-based interaction, so that the viewer would perceive the scenes as close as possible to real intuitive interactions (looking around) while exploring the "views".

6.1.2.2. Information Architecture

The experience unfolds along three options modules. Each module features a common narrative structure that develops across five sections: “Source”; “Molecular Signature”; “Context Story”; “Call for Action” and “Appeal” (Figure 28). The contents provide information about molecules, location, economic activity, cultural tradition, as also environmental impacts and pro-environmental behaviour recommendations to mitigate them.

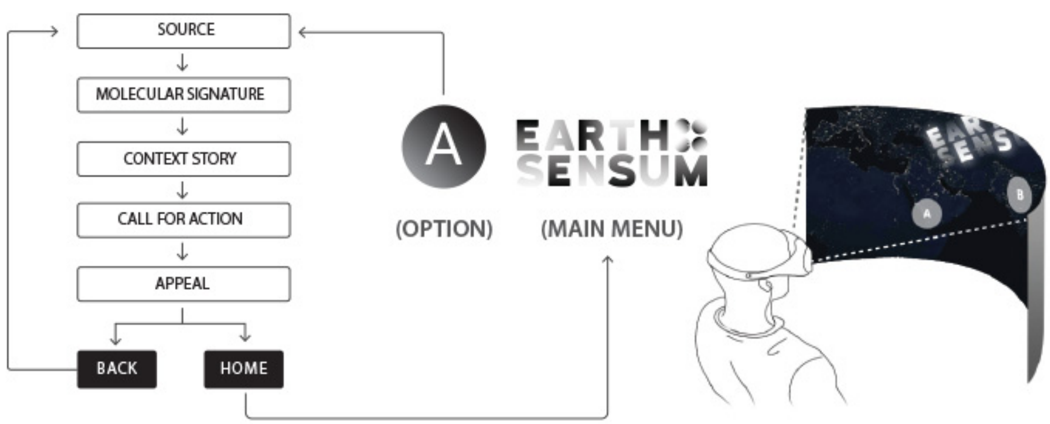


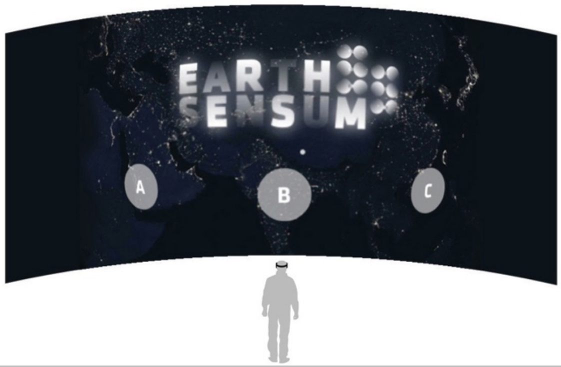
Figure 28 – Information architecture of a single MVR experience module.

See the complete information architecture system in Appendix D2.1 (Figure 47).

6.1.2.3. Storyboard

The Storyboard helps to plan and organize the content narrative (storytelling). In the context of VR medium, it helps further to visualize interaction behaviours. *Earthsensum's* VR Storyboard defines the content structure and interaction modes that each experience module follows (Figure 29, Figure 30, Figure 31).

1



Scene: Home

Main UI Zone: Scene option.
Description: Background Image is loaded displaying menu buttons options.

2

Scene: Source

Main UI Zone: Graphic animation of the option icon.
Description: Image and background sound is loaded.

3

Scene: Source

Main UI Zone: Text and Graphic animation.

Description: Graphic animation of "Entry" message. Smell experience: "Know Your Environment and Follow this Smell". Taste experience: "Know Your Environment and Follow this Taste".

4

Scene: Source

Main UI Zone: Text and Graphic animation.
Description: Graphic Animation indicating to "Breath".
Locution audio: Information about Smell / Taste source

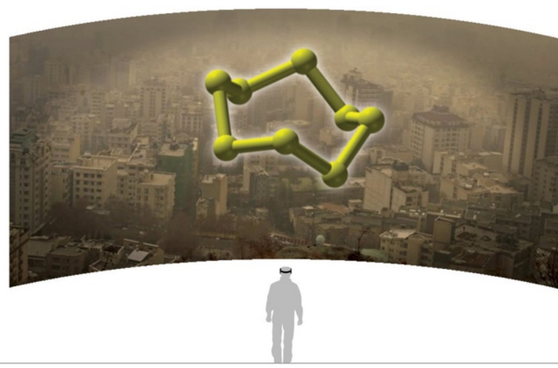
Figure 29 - MVR Storyboard Frame 1-4

5

Scene: Source

Peripheral Zone: Interaction target (Molecular Signature).
Description: The viewer has to turn his head to observe "Molecular Signature" option. Eye gaze activates scene loading.

6



Scene: Molecular Signature

Main UI Zone: 3d Model.
Description: The three-dimensional-molecule model is floating on the scene, related to the smell/ taste source.
Locution Audio: Identification and information about the molecule.

7

Scene: Molecular Signature

Peripheral Zone: Interaction target (Context Story).
Description: At conclusion of previous locution audio "Context Story" option is displayed.

8

Scene: Context Story

Description: New scene image is loaded.
Locution Audio: Information about interdependencies of stimuli source and socio-economic factors.

Figure 30 - MVR Storyboard Frame 5-8

9

Scene: Context Story

Peripheral Zone: Interaction target (Call for Action)

Description: New scene image is loaded.
Locution Audio: At conclusion of previous locution audio "Context Story" option is displayed.

10

Scene: Call for Action

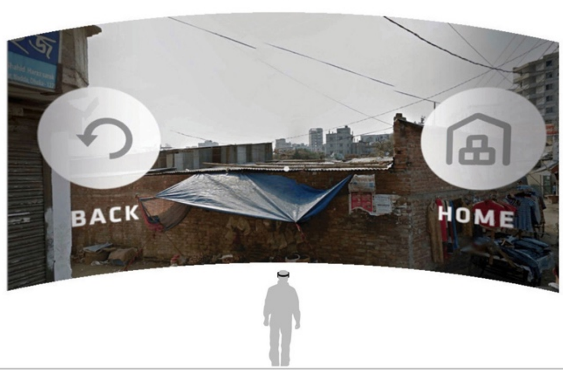
Description: New scene image is loaded.
Locution Audio: Pro-environmental recommendations.

11

Scene: Call for Action

Main UI Zone: Text and Graphic animation
Description: Final "Exit" message for smell experience: "Have a Taste of this Environment"; for taste experience: "Have a Smell of this Environment".

12



Scene: Appeal

Main UI Zone: Navigation options
Description: The navigation menu "Back" and "Home" is loaded. "Back" option allows to start the the content from the start. "Home" option loads the Main Menu .
Locution Audio: Recommendations about pro-environmental behavior.

Figure 31 - MVR Storyboard Frame 9-12

6.1.2.4. Functional specifications

Following we conceptualized and realized the content flow and locution narrative of each module: Smell A (Table 4); Smell B (Table 5); Smell C (Table 6); Taste A (Table 7); Taste B (Table 8) and Taste C (Table 9).

Table 4 - MVR content flow of Smell A option.

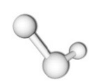
Smell A				
Theme		**Location**		
Pulp Industry - Cellulose		Lat: 40.055572 , Long: -8.880128 Leirosa, Portugal		
CONTENT FLOW				
Scene Target	**360º Imagery**	**Graphic Animation**	**3d Model**	**Locution**
SOURCE	360-Celbi-1.JPG	1. Entry-Smell.mov 2. Breath.mov		*The transformation process of cellulose liberates Hydrogen Sulfide.*
MOLECULE SIGNATURE	360-Celbi-2.JPG			*You are smelling Hydrogen Sulfide.*
CONTEXT STORY	istreetview			*The pulp and paper industry are one of the most successful in Portugal. In 2016 Portugal's Wood pulp export was $3,2M. Main Export partners are Spain and Turkey. Eucalyptus plantation contributes to soil erosion. Enhanced rainfall deficit can lead to desertification and consequently to environmental health vulnerability.*
CALL FOR ACTION	istreetview			*How does Hydrogen Sulfide feel like?* *How does Hydrogen Sulfide tastes?*
APPEAL	360-Celbi-1.JPG	Smell- Exit.mov		*What can you do for your environmental health? Use paper wisely!*
Background Audio	https://www.soundbible.com/340-Bird-Song.html https://www.soundbible.com/1397-Car-Driving.html			
Image Direct Link	https://www.instantstreetview.com/@40.054771,-8.866742,5.15h,5p,1z https://www.instantstreetview.com/@40.053199,-8.865728,274.51h,5p,1z			

Table 5 - MVR content flow of Smell B option.

Smell B				
Theme		**Location**		
Solid Waste Industry - Ammonia		Lat: 38.7444, Long: -9.331031 Mafra, Portugal		
CONTENT FLOW				
Scene Target	**360º Imagery**	**Graphic Animation**	**3d Model**	**Locution**
SOURCE	360-Lixo.JPG	1. Entry-Smell.mov 2. Breath.mov		*The transformation process of solid waste, Ammonia is liberated.*
MOLECULE SIGNATURE	istreetview			*You are smelling Ammonia.*
CONTEXT STORY	istreetview			*Waste management is an activity of public interest. It is safe to live near a waste management station but it can cause you environmental stress. Improper Waste Treatment practices contributes to air, soil and water pollution.*
CALL FOR ACTION	istreetview			*How does Ammonia feel like?* *How does Ammonia tastes?*
APPEAL	360-Lixo.JPG	Smell- Exit.mov		*What can you do for your environmental health? Reduce your waste! Use paper and plastic wisely! Waste prevention and recycling reduce the amount of waste sent to incinerators, lowering the greenhouse gases emitted when waste burns!*
Background Audio	https://www.soundbible.com/635-Wind.html https://www.soundbible.com/1734-Faulty-Mechanics.html			
Image Direct Link	https://www.instantstreetview.com/@38.744959,-9.326482,178.86h,5p,1z https://www.instantstreetview.com/@38.740444,-9.33721,92.09h,5p,1z			

Table 6 - MVR content flow of Smell C option.

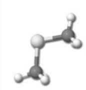
Smell C				
Theme	**Location**			
Natural Ecosystem - Seacoast	Lat: 38.804254° , Long: 9.484806° Praia da Adraga, Portugal			
CONTENT FLOW				
Scene Target	**360º Imagery**	**Graphic Animation**	**3d Model**	**Locution**
SOURCE	360-Celbi-1. JPG	1. Entry-Smell. mov 2. Breath.mov		*In the ocean, dimethyl sulfide is emitted to the atmosphereby bacteria when eating dying phyto-plankton.*
MOLECULE SIGNATURE	360-Celbi-2. JPG			*You are smelling Dimethyl Sulfide.*
CONTEXT STORY	istreetview			*Seabirds and other ocean animals use the smell of dimethyl sulfide to identify areas rich in phy-toplankton, which attract fish. Dimethyl Sulfide is normally present at very low levels in the hu-man body, namely in blood, urine and on expired breath. In the atmosphere, Dimethyl sulfide also helps to form clouds. Dimethyl sulfide is used in petroleum refining and in ethylene production. Ethylene is the chemical industry's primary building block, with over 60% of the raw mate-rial produced, being used in the plastic industry. Plastic pollution of marine-ecosystems leads into Fish eating micro plastic.*
CALL FOR ACTION	istreetview			*How does Dimethyl Sulfide feel like?* *How does Dimethyl Sulfide tastes?*
APPEAL	360-Celbi-1. JPG	Smell- Exit. mov		*What can you do for your environmental health? Reduce plastic consumption! Always recycle plastic waste! Waste prevention and recycling reduce the amount of waste sent to incinerators, lowering the greenhouse gases emitted when waste burns. Buy sustainable seafood products. Always ask the person you buy fish from where and how their fish is caught. Avoid bottom trawling and pair trawling fishing.*
Background Audio	https://www.soundbible.com/1935-Ocean-Waves.html https://www.soundbible.com/2193-Flock-Seagulls.html			
Image Direct Link	https://www.instantstreetview.com/@38.804254,-9.484806,2.74h,5p,1z https://www.instantstreetview.com/@38.809573,-9.479076,271.34h,5p,1z			

Table 7 - MVR content flow of Taste A option.

Taste A				
Theme		**Location**		
Plastic Industry - Spinach		Lat: 35.715298 , Long: 51.404343 Tehran, Iran		
CONTENT FLOW				
Scene Target	**360º Imagery**	**Graphic Animation**	**3d Model**	**Locution**
SOURCE	istreetview	1. Entry-Taste. mov 2. Breath.mov		*You are tasting Spinach. Chlorophyll is responsible for its green pigment and minty flavour. Chlorophyll contains Hydrogen atoms.*
MOLECULE SIGNATURE	istreetview			*Chlorophyll.*
CONTEXT STORY	istreetview			*Ancient Persia is considered the birthplace of spinach before it spread to India, China and Europe. Iran has a major Air Pollution Index from vehicle emissions, refinery operations and industrial effluents, especially in urban areas. Current issues contemplate also water pollution from raw sewage and industrial waste. Tehran is ranked high for severe fine particle air pollution globally, leading to unhealthy air pollution levels. Iran's main export trade is Crude Petroleum and the main import trade are Cars. Iran's second export trade is Ethylene Polymers for the chemical industry. Hydrogen atoms are applied in Ethylene production, used for plastic bags, food containers, and packaging in general. American Federal data has listed Spinach to contain the highest levels of pesticides residues. Main fresh Spinach exporters are the United States, Spain and Italy where Ethylene is applied in Spinach leaves packaging.*
CALL FOR ACTION	istreetview			*What you are tasting contains compounds which are found in materials which contributes to environmental stress of Tehran's and of global citizens. How does Chlorophyll makes you feel? How does Tehran tastes?*
APPEAL	istreetview	Taste-Exit. mov		*What can you do for your environmental health? What can you do for Tehran's environmental health? Reduce Plastic Consumption! Buy fresh Spinach from your local organic food producer.*
Background Audio	(Soundsnap.com) Tehran-atmos.wav			
Image Direct Link	https://www.instantstreetview.com/@35.692002,51.36443,89.12h,5p,1z https://www.instantstreetview.com/@35.692002,51.36443,89.12h,5p,1z https://www.instantstreetview.com/@35.697268,51.369448,251.7h,5p,1z https://www.instantstreetview.com/@35.664816,51.359608,257.93h,5p,1z https://www.instantstreetview.com/@35.809123,51.355816,128.82h,5p,1z https://www.instantstreetview.com/@35.756309,51.304282,70.21h,5p,1z			

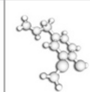
Table 8 - MVR content flow of Taste B option.

Taste B				
Theme		**Location**		
Meat Production Industry - Soy		Lat: 35.715298 , Long: 51.404343 Tehran, Iran		
CONTENT FLOW				
Scene Target	**360º Imagery**	**Graphic Animation**	**3d Model**	**Locution**
SOURCE	istreetview	1. Entry-Taste.mov 2. Breath.mov		*You are tasting Soy. Soysauce gives it a savory flavour. Soysauce is made of fermented paste of Soybeans. 100gr of Soybeans contains 9% of water and 5% of ash.*
MOLECULE SIGNATURE	istreetview			*Water.*
CONTEXT STORY	istreetview			*Although the soybean originated in China, 60 % of all soybeans entering international trade go to China. Main Soybean importers are the United States and Brazil. Explosive growth of soybean consumption in China is linking to soared consumption of pig meat, poultry and fish, which farming industry are feed by soybean meal. Only one tenth of the soybeans used in China is consumed directly as food such as tofu and soy sauce. But Soybeans world demand is still rising, putting on pressure for more land requirement. Since USA has no additional land that can be planted to soybeans, Brazilian Amazon Basin is offering new land leading to deforestation, loss of biodiversity and increased carbon emissions. The same effects of deforestation, urbanisation and industrial development causes the capital of China to be listed as one of the most polluted cities in the world.*
CALL FOR ACTION	istreetview			*What you are tasting contains compounds which are found in the air and the ground, hence contributes to environmental stress of Beijing's citizens and global citizens. How does Soy make you feel?* *How does Beijing tastes?*
APPEAL	istreetview	Taste-Exit.mov		*What can you do for Beijing's environmental health? Reduce Meat Consumption!*
Background Audio	(Soundsnap.com) Tehran-atmos.wav			
Image Direct Link	https://www.instantstreetview.com/@39.907256,116.375481,173.56h,5p,1z https://www.instantstreetview.com/@39.919253,116.25768,197.76h,5p,1z https://www.instantstreetview.com/@39.893619,116.386644,196.93h,5p,1z https://www.instantstreetview.com/@39.773458,116.229318,192.42h,5p,1z https://www.instantstreetview.com/@39.940013,116.428448,157.09h,5p,1z https://www.instantstreetview.com/@39.938812,116.427234,146.03h,5p,1z			

Table 9 - MVR content flow of Taste C option.

Taste C	
Theme	**Location**
Garment Industry - Clove	Lat: 23.777176, Long: - 90.399452 Dhaka, Bengladesh

CONTENT FLOW

Scene Target	**360º Imagery**	**Graphic Animation**	**3d Model**	**Locution**
SOURCE	istreetview	1. Entry-Taste. mov 2. Breath.mov		*You are tasting Biryani Rice. Cloves gives it a warm flavour. In clove oil Eugenol is found, responsible for clove aroma.*
MOLECULE SIGNATURE	istreetview			*Eugenol*
CONTEXT STORY	istreetview			*Cloves are commercially harvested primarily in Bangladesh which contributes to Eugenol extraction. Eugenol contains hydrocarbons. Hydrocarbons are used in Natural Gas and Fuels, Plastic, Paraffin and Asphalt.Pollution Index of Bangladesh occupies a top position - regarding Air and Water pollution. Major export commodities of Bangladesh are Garment Textile led by Non-Knit Men's Suit. The top import product is Heavy Pure woven Cotton. Top import origins are China and India. Top export partners are the European Union and the United States*
CALL FOR ACTION	istreetview			*What you are tasting contains compounds which are found in materials which contribute to environmental stress of Dhaka's citizens and global citizens. How does Cloves make you feel? How does Dhaka smell*
APPEAL	istreetview	Taste-Exit. mov		*What can you do for your environmental health? What can you do for Dhaka's environmental health? Buy clothes wisely.*
Background Audio	(Soundsnap.com) Dhaka-atmos.wav			
Image Direct Link	https://www.instantstreetview.com/@23.811389,90.421289,74.64h,5p,1z https://www.instantstreetview.com/@23.808474,90.42146,4.57h,-17.91p,1z https://www.instantstreetview.com/@23.801552,90.361896,120.93h,-7.97p,1z https://www.instantstreetview.com/@23.808689,90.423702,80.86h,5p,1z https://www.instantstreetview.com/@23.810539,90.39212,258.9h,5p,1z https://www.instantstreetview.com/@23.805155,90.382411,275.38h,5p,1z			

6.1.2.5. Asset production

After having systemized the global information architecture (Appendix D2.1 - Figure 47) we established for each experience module the asset production requisites. We undertook the production of all necessary media components. Graphic and motion design was created with Adobe® Creative Cloud™. In this line, we developed *Earthsensum's* "visual identity (Appendix D1 - Figure 45 and Figure 46). Following the visual design theme, we created UI components and animations (Appendix D2.2 - Figure 48 and Figure 49). Images were taken with "Samsung Gear 360 Camera", otherwise we used "Street View Download 360" online tool [269] (Appendix 2.4 - Figure 50). Online sound libraries provided the background audio [270], [271], while locution was recorded with Voice Memo App for iPhone. Finally, digital 3D model libraries [272] granted the molecule models (Appendix D2.2 - Figure 48).

6.1.2.6. Low-Fi prototype

Creating basic prototype demos and user-testing them, allows refining design decisions. The first step is producing a Low-Fi prototype, with sketches or images. We were concerned about the placement of UI components in the virtual environment (Figure 32). This was achieved with GoPro VR Player [273]. It is a 360-degree content viewer which allows interacting with 360° videos and 360° panoramas on desktop computers and Oculus Rift. The test helped to review menu placement, sizes and proportions, as also content flow (Figure 33).

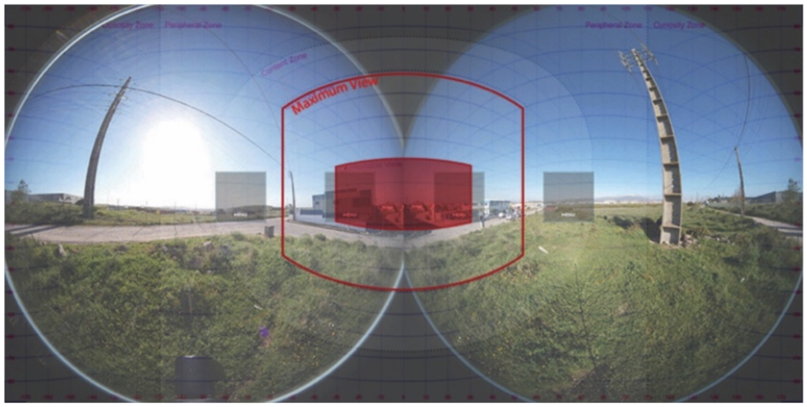


Figure 32 - Panorama Grid and Canvas Size view over 360-degree spherical image.

Figure 33 -Low-Fi testing on local desktop computer with Go Pro Player.

6.1.2.7. High-Fi prototype

High -Fidelity prototypes cover more dimensions of the desired experience. Interaction zones considered the range of motion recommendations. Primary interaction targets were placed on the main UI zone for easiness. The secondary menu for switching between scenes was placed on the peripherical zone, to stimulate content exploration through head movement. All graphic elements, motion graphics and 3d Models were placed along a depth axis of 1m to 10m, to guarantee comfortable depth and content separation effects. This was achieved by using Unity3D [274] and following the information architectures and content specifications.

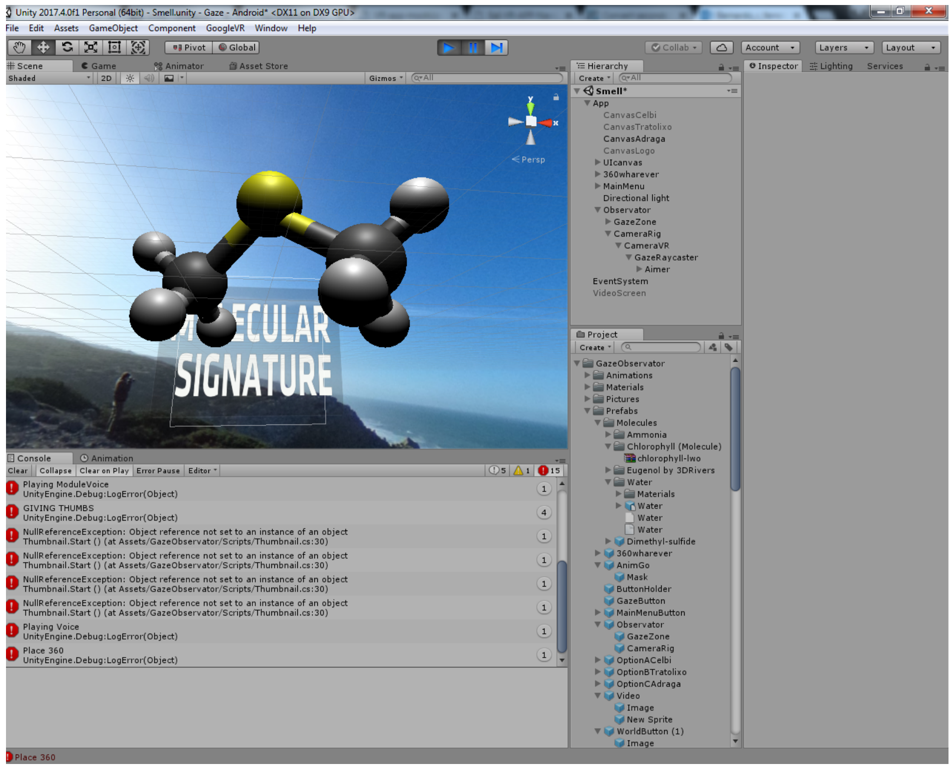


Figure 34 - Implementation in progress with Unity 3D.

For evaluation purposes, the experience was coded to obligate the viewer to assist each scene from beginning to end, and so assuring the experiment mission. As this decision constrains the user experience, we included a status bar to inform the viewer about the content time length for each scene. Finally, the demo prototype was exported as a standalone app.

Earthsensum's MVR contents are accessible online with a password:

- **MVR Smell A:** https://vimeo.com/353220905
  password = earthsensum-vr-smell-1

- **MVR Smell B:** https://vimeo.com/353221130
  password = earthsensum-vr-smell-2

- **MVR Smell C**: https://vimeo.com/353219095
  password = earthsensum-vr-smell-3

- **MVR Taste A:** https://vimeo.com/353218005
  password = earthsensum-vr-taste-1

- **MVR Taste B:** https://vimeo.com/353218548
  password = earthsensum-vr-taste-2

- **MVR Taste C:** https://vimeo.com/353217542
  password = earthsensum-vr-taste-3

6.1.3. Evaluation methodology

We used mobile device Samsung Galaxy S8 coupled with Samsung Gear VR, a standalone Head Mounted Display (HMD). At the start of the session, participants were given a spoken introduction and written task scenarios to complete:

- Smell Experience Task - "You pass by a location. A distinguished smell has an impact on you. You want to know more about this smell".
- Taste Experience Task - "You pass by a street food market. You have tasted a certain ingredient. You want to know more about this ingredient".

6.1.3.1. Procedure

We explained the navigation settings and demonstrated them on an external screen and handed out the HMD. Next, participants tested the VR experience while seated in a revolving chair as recommended for experiments involving 360-degree contents [275]. We applied the walkthrough method [48] for the prototype evaluation. We took notes about verbal and non-verbal clues while keeping an eye on what the participant was looking at and how they interacted (Appendix A5). Additionally, we recorded navigation flow and body movements.
At conclusion, we inquired about the system experience, content experience, relevance and impact on environmental awareness. Participants answered questionnaires and were asked to rate the statements (1 = *"Strongly Disagree"*; 5=*"Strongly Agree")* with button boxes. For navigation and presence inquiry, we adapted Witmer's questionnaire [276]. Relevance evaluation statements comprised: "I learned something new"; "I consider this content experience useful" and "I would recommend this experience as an educational tool".

Environmental awareness impact statements contained: "Experiencing this content makes me improve my awareness about my environment"; "Experiencing this content makes me think about my behaviour towards my environment" and "Experiencing this content inspires me to take positive action towards my environment".

6.1.3.2. Results

- **UX evaluation**

All 16 participants executed movements and navigation actions with success. Navigation targets were recognized “easily” - smell group: 75% (n=6); taste group: 100% (n=8). Presence perception of having a sensation of being in the real place was “somehow” for 50% (n=4) of each group. The scenes were enjoyed by the average of total 16 participants. The most also rated contents as comprehensible.

- **Content experience evaluation**

The average of each group (75%) (n=6) affirmed that a clear message was provided.

- **Relevance evaluation**

Usefulness.
Near all rated the content experience as useful - smell group: 75% (n=6); taste group: 87,5% (n=7).

Education.
Out of total 16 participants, 68,75% (n=11) stated they learned something new. The average - 75% (n=12), would recommend the VR App as an education tool.

- **Impact evaluation**

Environmental Awareness.
The average affirmed that the content experience increased their environmental awareness - 68,75% (n=11). Moreover, 75% (n=12) expressed that the experience made them think about their behaviour towards the environment. Fourteen participants (87,50%) declared that it inspired them to foster pro-environmental behaviour. Figure 40 presents evaluation results after user experience of the MVR app (left) and the MAR app demo (right).

Complementary information:
The overall quantitative results are available as data visualization in Appendix F1.

A selection of MVR User Experience observations is accessible online with a password:

- VR-UX-Smell-2: https://vimeo.com/361533355
  password = earthsensum-vr-ux-2

- VR-UX-Smell-4: https://vimeo.com/361533610
  password = earthsensum-vr-ux-4

- VR-UX-Smell-3: https://vimeo.com/361533226
  password = earthsensum-vr-ux-3

6.2. Design hypothesis 2: *Earthsensum* design case with augmented reality technology

Earthsensum's Augmented Reality (AR) experience concept was ideated based on design hypothesis 2 formulation. This concept encompasses context-related information, relating to studies such as the perception of geolocation, spatial narratives and sense of place [277]. This design purpose relies on the latest advances of 5G networks and cloud computing as providers of the technological requisites necessary for its feasibility. The fifth-generation wireless (5G) latest iteration of cellular technology promises spatial web expansion, benefiting AR and VR products consumption [278], [279]. AR Cloud technology takes advantage on 5G adoption, as it promises to build a persistent 3D digital copy of the real world to enable sharing of AR experiences across multiple users and devices. To this end, it uses continuously updated collections of point cloud datasets and descriptors aligned with real-world coordinates [280], [281].
With AR Cloud technology it is possible to label a geographic coordinate. Hence, we induce that the user is empowered to metaphorically "own" specific geolocations - *in situ* or remote, and so co-narrate its representative significances. This feature is the backbone of *Earthsensum's* MAR app concept, which envisions the human as the main sensor input device, enabled to annotate, communicate and share chemical sense experiences across a digital platform.

Considering the early design stage of prototype development, these technological features would be complex to implement. Therefore, we decided that these would be simulated with graphics and its user evaluation would run on a regular computer as recommended by research-based User Experience leader Nielsen [52]. Thus, our design process implied to contemplate MAR App Design and User Interface design guidelines, as required by established Usability Principles [53], [54].

In general, mobile application design is recommended to develop along with six main phases [282], [283]: (1) understanding target profile and expectations; (2) technology trends and guidelines; (3) conceptual wireframing; (4) visual design wireframing; (5) feature implementation for rich experiences; and (6) evaluation through user-experience tests. Accordingly, we adapted *Earthsensum's* MAR app design process contemplating: product concept (hypothesis formulation 2); AR design guidelines research, information architecture, functional specifications mapping, content development, Low-Fi wireframing, visual design development, Hi-Fi wireframing and finally UX evaluation. With regard to *Earthsensum* MAR design process , it evolves also along several phases: information architecture, functional specifications mapping and content development, low-fi wireframing, visual design development, high-fi wireframing and UX evaluation.

6.2.1. AR design guidelines

At the moment of writing this work, design guidelines for AR design are mainly provided by leader tech companies: Apple Inc. [284] and Google [285]. They provide the AR development framework: Google offers ARCore for Android and Apple proposes ARKit for iOS smartphones. However, AR design guidelines research has emerged for specific user case scenarios such as AR UX applied to an Aircraft engine repair manual [286].

Overall, AR design guidelines are systemized around main themes:

- Environment (definition and experience size)
- User (movement, safety and comfort)
- Content (realism, content placement and manipulation)
- Interaction (UX and UI design)

Following, we present herein the essential recommendations for each theme.

6.2.1.1. AR user experience guidelines

- Environment

Physical and Virtual environments concepts - Physical environments are varied as they might contemplate a small apartment to a vast field. As such obstacles like for example furniture or vehicles represent physical challenges. Virtual augmented environments merge real-world image captured from a device's camera with virtual content, such as 3d objects or interactive information. It depends on the correct perspective alignment of the virtual camera that renders 3D content and the device's camera. Therefore, the experience should fit the environment and consequently the size of the interaction space.

- User

Movement – The user should be encouraged to move around. However, movement requirements should avoid user fatigue. Four user modes are foreseen which shape the "immersive" experience: seated hands fixed; seated hands moving; standing hands fixed; and standing hands moving (full range of motion).

Safety - User safety recommendations include interaction targets not making the user walk backwards. Encouraging the user to move in any direction while the device is pointed elsewhere is not recommended. Interaction design has to assure user awareness of its surroundings, without frustrating the AR experience.

- **Content**

Realism – AR objects should blend to the physical world and should engage with their environment. When integrating 3D objects, they should contemplate life-size scale and placed all facing the same direction.

Content placement - Object placement should allow depth and distance perception. Three distinct areas are recommended: downstage, upstage, and centre stage. Downstage is closets to the user and is suggested to examine something closely. Upstage is farthest from the user and is advised when the scope is encouraging exploration and movement. Centre Stage is the most comfortable viewing range for users to interact with. Objects should be placed at a comfortable distance in the scene controlled by setting default maximum distance.

Depth collisions –Interaction space requirements should be communicated at experience start.

Content Manipulation –Virtual objects should offer interaction features, achieved through translation, rotation, scaling and proximity.

6.2.1.2. AR User Interface Guidelines

- **Interaction**

Initialization – Transiting from 2D screen into AR has to be evident.

Landscape & Portrait Modes - Support for both portrait and landscape modes should be available. In case of impossibility, the one that's best fit the experience is provided.

Guides and Instructions - Tutorial and visual guides should be embedded into the experience flow.

Minimize the Input - User experience should be smooth. Therefore, simplicity and consistency are mandatory. The user should be able to trigger an action effortlessly, without looking at it. Hence, taking the user out of a scene too often has to be avoided.

Interface – The screen should display as much of the physical world and virtual objects as possible. Hence, UI controls and information have to remain to the essential.

Offscreen and Audio Exploration – Visual and audio cues should be applied to encourage movement and exploration. Integrating audio improves also the immersive effect.

Text readability - Text used for labels, annotations, and instructions should be displayed as if it is attached to the mobile screen rather than in the virtual space. The text should face the user and be shown at the same size regardless of the distance of the labelled object.

Haptic feedback – Google guidelines recommend to avoid haptic feedback in AR experiences. It is justified by unpredictable technology variances between different Android phones, causing AR tracking lost. However, the Apple Developer Team encourages haptic feedback on iPhone devices, to enhance the interaction experiences.

6.2.2. Design development

Following the hypothesis 2 formulation, our product concept encloses chemical sense communication linked to environmental information. In this line we conceptualized a service that targets the non-scientific public, considering the following features:

- Create, join or share a smell or taste annotation with the service user community.
- Delivery of geolocation-based information.
- Delivery environmental health education information.
- Motivating pro-environmental behaviour with community building.

6.2.2.1. Concept

Earthsensum MAR app offers the symbolic of smell and taste perceptions. These allow building a personal visual symbol of a personal sensorial perception based on the geolocation. Signing up to the *Earthsensum* community allows the user to "scan" the geographic area for previous "geo-labelled" experiences and decide to "join" or to "place" a symbol. To join a symbol means that a predominant sensory experience is prevailing in the area. To "place" a new symbol represents a new experience. Finally, the user is able to consult, connect and share this data with the community (Figure 35). Additional information is provided through main content sections of "Molecules" and "Take Action". The "Molecules" section enables to access of molecule information as also air quality indicators pulled by official data sources in real-time [287]–[289]. Its most accentuated indicator determines what molecular information is displayed. By contrast, the taste experience is labelled by its ingredients. Databases identify the most common molecule presence for an ingredient (e.g.

Spinach – Chlorophyll) and provide information about the main export country [253]. This process enables to approach air quality indexes of the remote location to which the ingredient is related. Finally, the "Take Action" section provides further contextualized information about social-economic and behaviour change information. Users are able to suggest their own pro-environmental actions to *Earthsensum's* community.

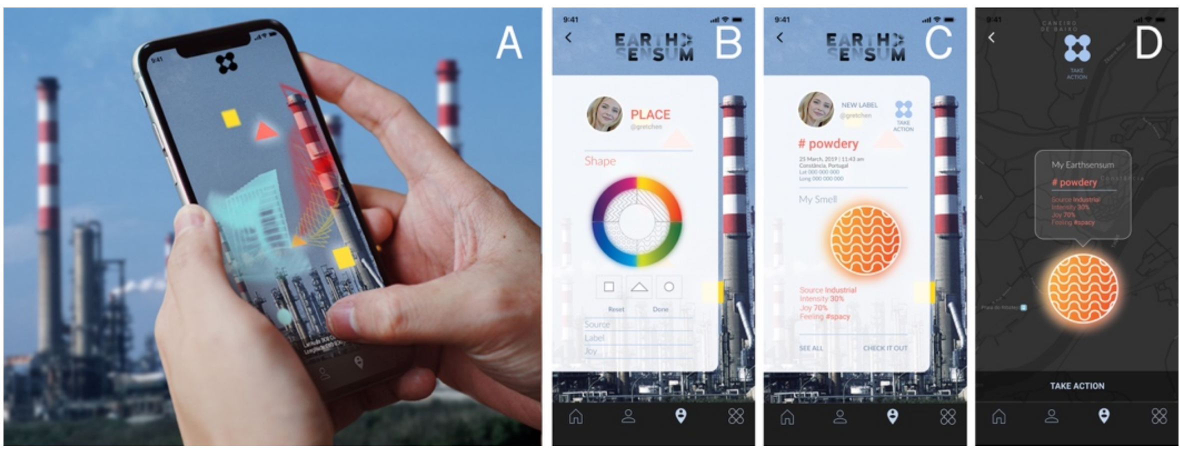


Figure 35 - MAR concept (a). Wireframes of association options (b), symbolic representation summary (c) and map view of icon placement (d).

6.2.2.2. Information Architecture

We build the information architecture diagram with online Lucidchart [290]. Appendix D3.3 - Figure 52 presents the main section categories and sub categories.

6.2.2.3. Functional Specifications

Following, we mapped out the functional specifications of the experience. (Appendix D3.2 -Table 12) with indications for function, description, requisitions, Information architecture module and component.

6.2.2.4. Content development

Accordingly, we researched and developed content information for each section (Appendix D3.2 - Table 13).

6.2.2.5. Low-Fi wireframing

Based on this structural process, we build a Low Fidelity Prototype using online Balsamiq [291] tool. Decisions at this design stage considered information overload avoidance by displaying symbols facing the same direction as the physical world. Map visualizations present symbols as floating layers. Main and second level menus display lists of related options following User Usability Principles [292]. For navigation fluidity, we applied navigation drawers for association components (Figure 36). This prototype test granted fine-tuning of graphic components placement navigation and content flow (Appendix D3.4 - Figure 53).

Figure 36 - Low-Fi Wireframes.

6.2.2.6. Visual Design

We created a visual language concept aiming to evoke the lightness of molecules that carry sensory information to our brain, resulting in the human perception process (Appendix D3.5 - Figure 54). All graphic elements and UI components were designed using Adobe® Creative Cloud™ [293].

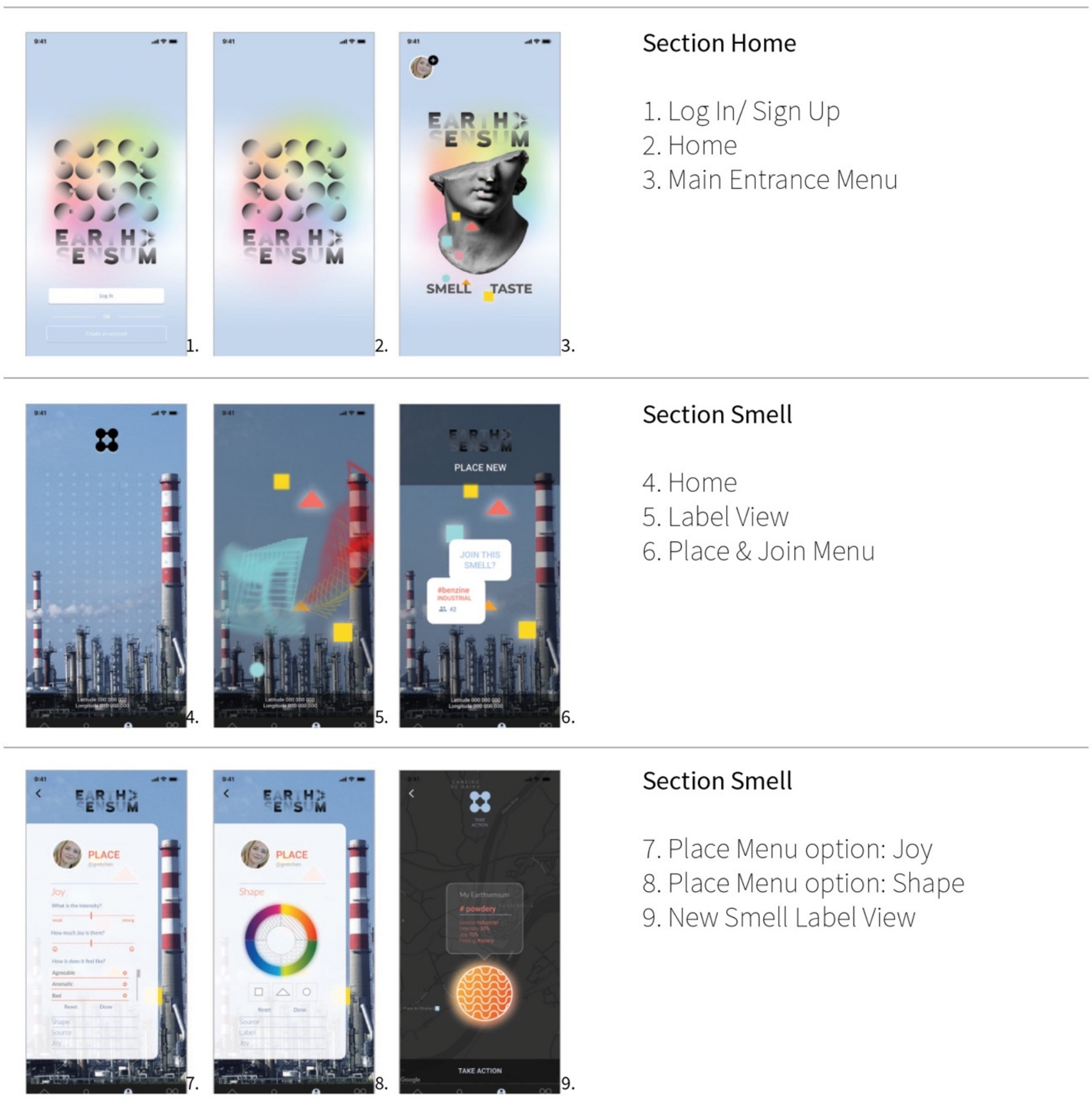
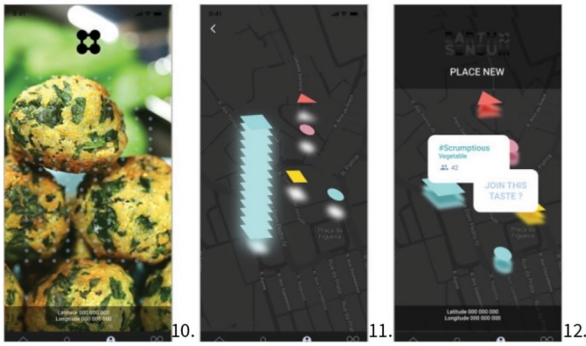


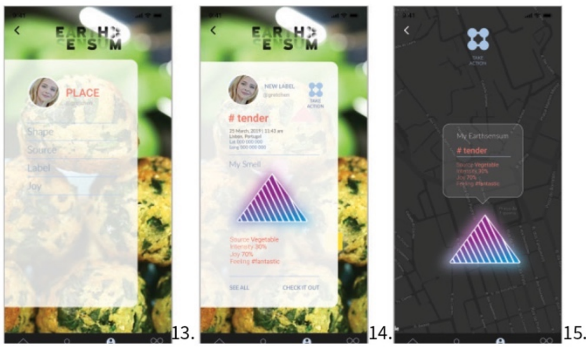
Figure 37 - Selection of High Fi frames according to Home and Smell sections.



10. 11. 12.

Section Taste

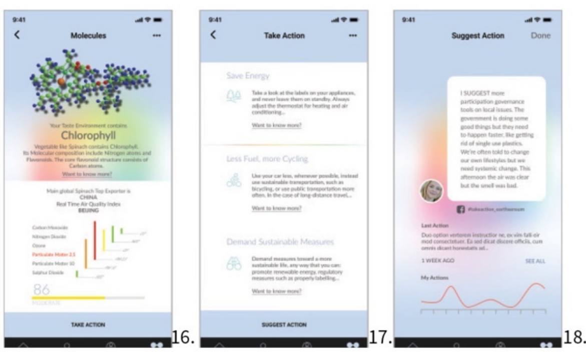
10. Home
11. Placed Label Visualization
12. Place New option



13. 14. 15.

Section Taste

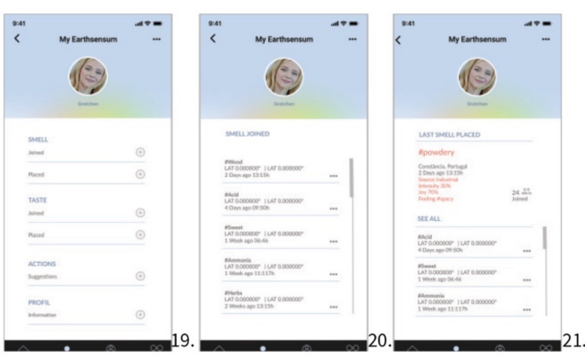
13. Place symbol options
14. New Symbol Confirmation
15. New Symbol Visualization



16. 17. 18.

Section Molecules

16. Molecule and Air Pollution information
17. Take Action Suggestions
18. Users Actions Visualization and
    Community sharing



19. 20. 21.

Section User

19. Personal Area Options
20. Joined Actions Summary
21. Joined Actions Detail

Figure 38 - Selection of High Fi frames according to Taste, Molecule and User profile sections.

6.2.2.7. High-Fi Prototype

Earthsensum High-Fi prototype (Figure 39) was build using the online tool Figma [294]. The platform allows converting static design files into interactive experiences by connecting UI components. At project conclusion it produces a sharable web-based presentation[13] that enables heuristic evaluation process [295].

Figure 39 - *Earthsensum* MAR High-Fi prototype.

[13] The interactive prototype can be viewed online: https://www.figma.com/proto/DBizXEhSzLwXZCcnU0beQanQ/Earthsensum?node-id=1%3A3&scaling=scale-down

6.2.3. Evaluation Methodology

The tests were planned to focus the method on the desirability of adoption (qualitative research). Task completion success or usability errors detection (quantitative research) was not our main concern at this point of our study. The goal of the test was to verify if the participants would comprehend, adopt and engage with the application concept. To this end, going through task completion would grant the desirability of adoption feedback. Hence, our evaluation method enclosed recording qualitative and quantitative data.

The heuristic evaluation was conducted applying the walkthrough method [296], using a Desktop Computer. At the start of the session, we introduced the product concept and its underlying technology with visual and spoken information. Next, we asked participants to complete three task scenarios:

- Task 1 - "You perceive a certain smell/ taste in your environment. You want to label and share this experience on your location".
- Task 2 - "You want to find out more about this kind of smell /taste".
- Task 3 - "You would like to have a more participative attitude towards your environment. You want to know how to take action".

6.2.3.1. Procedure

We applied the first click testing method [47] and took notes of participants interaction behaviour (Appendix A6). After the test, a web-based questionnaire was provided, complemented with final open-ended questions.

Altogether, we inquired about the system experience, content experience, relevance, usefulness, satisfaction and impact on environmental awareness. We provided self-report questionnaires with Likert evaluation scale (5-point) asking participants to rate statements *(1= "Strongly Disagree"; 5= "Strongly Agree")* with button boxes. Additionally, we conducted semi-structured interviews.

The relevance statements covered: "I am now more aware of my sense of smell/taste."; "This annotation system enables me to express my smell/ taste experience.";

Usefulness statements included "I consider this App experience useful." and "I would recommend this App as an education tool.". Additionally, we provided a text field with the question "Why?".

Satisfaction statement "I enjoyed the content experience." Was complemented asking "What did you like most?" and "What could be improved?".

The impact evaluation statement consisted of "This annotation system increases my environmental awareness".

6.2.3.2. Results

In this section we describe the results of the usability test and environmental awareness impact.

- **UX Evaluation**

We observed participants complete the three task scenarios without major hesitations. Total 16 participants (100%) declared they recognized navigation targets easily.

- **Relevance evaluation**

  Out of total 16 participants, 87,50% (n=14) declared that the symbolic annotation system enabled them to communicate smell or taste experiences.

- **Usefulness evaluation**

  Except for one participant - 93,75% (n=15) - stated that the content experience was useful and would recommend the MAR app as an educational tool. Usefulness ratings showed that participant perceived education and information as an advantageous outcome.

  Eleven participants (68,75%) mentioned the benefit of having a holistic view of the chemical senses and environmental health topics:

  "(...) because we can learn more about all sorts of smells and prevent ion measures" *(P4);*

  "We can be more aware of the characteristics of the place around us" *(P7);*

  "People can learn more about a particular flavour and its entire process until it reaches us" *(P12);*

  "Science, art, poetry is connected, and a part of our philosophy and senses. So, the apparent reality reflects our five senses, therefore this App helps to improve this kind of awareness". *(P16)*

  Two participants (12,25%) emphasized the symbolic representation system as a useful tool to improve communication and health:

  "A great association between smells and their logical visual representations" *(P5);*

  "I find it helpful annotate my taste experience. I also think it is useful to share these experiences between people. For the information that they can have access in relation to these problems. To become healthier" *(P13).*

Reasons for recommending the MAR app as education tool were arguments about education, awareness and innovation:

Education.

Participants identified two target groups as ideal audiences for the MAR app: "Kids" and "Students". Hence, from the participants perspective, younger age groups would benefit from the AR concept product because:

"This type of interactive applications is quite useful for kids"(P1); *"To help our children to improve their environmental skills and perception of the smells"(*P7) and *"(…) students can learn a lot more from this application"* (P4). Moreover, the MAR App is *"Easy to use, fun, and teaches the relationships between pollution sources and smells"* (P5), and *"(...) how they can affect someone's day-to-day life"*(P7). Shortly*, "Because it teaches important matters"(*P14).

Environmental Awareness.

Three participants (18,75%) affirmed that the interactive content and experience would boost environmental awareness and understanding of interdependencies:

"Raising awareness about certain pollution and bad habits, etc." *(P2).*

"It helps to understand more about the global problems that exist in relation to the environment" *(P13).*

"It also helps to make people aware of what goes on in the world in terms of the environment" *(P14).*

Innovation.

Finally, three participants (18,75%) were captivated by having been guided though a meaningful experience revealing new perspectives.

"I recommend this application because for children it will be a funny experience" *(P3).*

"It would be a more interactive, new and different approach than the usual and it would make everything more interesting" *(P12).*

"Because it is time to stop dividing science and to start understand as a whole. This App allows to consider a holistic understanding of complexity" *(P16).*

- **Satisfaction evaluation**

Out of 16 participants, all declared they enjoyed the content experience. Most appreciated aspects were aesthetics and content experience, besides content features and the symbolic representation system.

Visual Design and UX.

The Visual design concept was emphasized by P1: “The graphical user interface and design language.”, complemented by P5 with the interaction concept: “The concept and interface design.”. P16 enjoyed the product concept: “The experience of being conducted by a narrative with the corresponding images. All the sections complement each other.” (P16)

*Education***.**

P2 and P10 stressed increased environmental literacy accomplishment: “More knowledge about certain environmental aspects.”; “It deals with environmental issues, and develops further.” Furthermore, content concepts were highlighted by P3 as: "What I liked the most was the information about the molecules." and P4: "Graphic Design and the contents about the molecules and the prevention measures.". However, P11 referred specially the sensorial related information: "Amount of information we can get about food." P13 liked most the correlation of environmental data and the sensorial experience: "I liked the part where you see the Air Quality Index of the countries. And to relate this information to what was tasted." P6 enjoyed the concept purpose envisioning pedagogic application: *"I liked everything because it was a well-structured and well-developed program that can help today's learning approach "*, mentioning P15 its goal: "Helping to sensitize people."

Symbolic Representation System.

Chemical sense annotation and sharing was highlighted by those who most enjoyed the core experience concept as exemplified by the following statements:

"Of being able to share the smell of local data with other people." (P8);

"Share information with others who may have different points of view." (P12);

"Social network and contribution to its intelligence of this annotation system." (P14)

Additionally, P9 stresses activism features: *"I liked most the ability of annotating our tastes on the map and take action to help change the environment."*

- **Improvement suggestion**

Overall suggestions cover mainly interaction, content and features improvements. P1 suggests usability improvements *"Navigation system: the submenu should not exceed three depth levels."*. Further content developments suggestion by P9 includes: *"Having more "take action" options."*, whereas P3 suggests enhanced social media features: *"Having friend network on the application."* Additionally, the map visualization mode took the attention of P7: *"The aspect of the map itself. I would like a more realistic map."*

Moreover, P10 suggest the reliable content source partnerships: *"Experts opinion/approval should be included through partnerships with ambient monitoring agencies (for meaningful and proven scientific information). "*(P2)

However, P5 asserts that *"As everything, it should be improved, but only on detail level. Works very well as it is."*, as also P6: *"Nothing is perfect and everything can be improved in the future, but at the moment this is great."*

- **Impact evaluation**

Out of 16 participants, 87,5% (n=14) stated that their environmental awareness increased after having engaged with the symbolic representation system (Figure 40 – right).

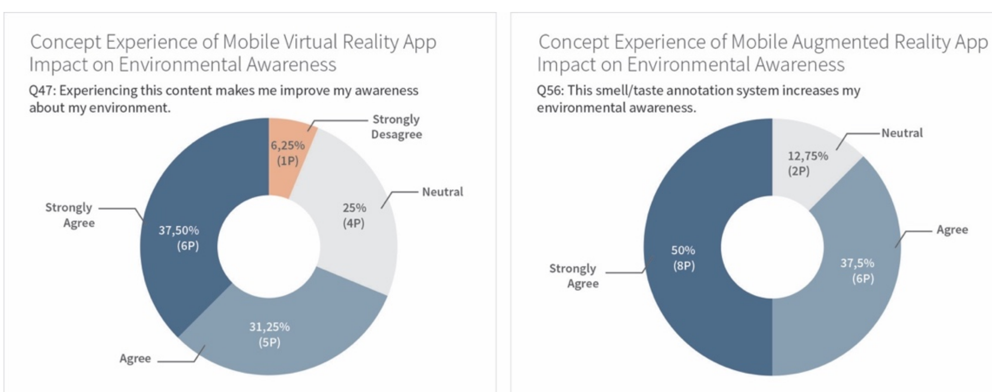


Figure 40 - Environmental awareness self-evaluation after user experience of the MVR App (left) and the MAR App demo (right).

Complementary Information:
The overall quantitative results are available as data visualization in Appendix F2.

Complementary Information:
Related to his section, we provided additional documents with this thesis**:**

- Document: Earthsensum_MAR_Prototype_diagram.pdf
- Interactive prototype: Earthsensum_MAR_Prototype_LowFi.pdf
- Wireframes: Earthsensum_MAR_VisualDesign_frames.pdf

6.2.4. Summary of design phase 2.

In this section of our research, we explored the meaning and communication construction layer of our Multisensory HCI design process. Using digital media, we provided the contextualization of smell and taste experiences. We conceptualized and developed two design hypotheses for prototype evaluation: (i) MVR experience for educational purposes addressing remote environmental events and (ii) MAR experience consisting of enhancing a smell and taste annotation system with local environmental information. Evaluation of these design concepts was positively evaluated in terms of system, user and content experience. Furthermore, results revealed awareness increment about chemical senses and environmental challenges, after the prototype experience. Regarding our goal to know if by providing tools to acknowledge and communicate smell and taste experiences, the common public could make sense of environmental events and make informed choices, our results are encouraging.

The Concept Evaluation

In the final step of our experiment, we carried out the overall evaluation of our conceptual assumptions regarding chemical sense and environmental communication investigation.

7. Proof -of-concept evaluation methodology

We asked quantitative questions about the conceptual design baseline, interaction model and comments.

7.1. Procedure

We provided a text field to record the answers and took notes.

The questions enclosed:

- "What do you think about communicating environmental health through smell/ taste perception?"
- "Which of the proposed interaction model would you prefer?"
- "Do you have other comments?"

7.2. Results

All 16 participants (100%) validated positively the concept as innovative and relevant. Arguments covered contribution to education; enhanced environmental awareness; innovation opportunity and insights into pitfalls. Herein we present a selection of quotes according to each argument theme.

- **Education**

Referring to environmental education P4 emphasized how environmental knowledge could increase, adding

P6 “(…) *because it is easy to understand and very effective”*. P10 and P9 refer that this approach incites people to know more what goes on outside in their own country.

"It deals with environmental issues and details. It's a good idea because we know more about other countries. By experiencing a flavour, we can think of the environment of those countries and under what conditions they are"*(P9).*

- **Awareness**

Chemical sense inclusion ignited a different viewpoint to explore the environment. P1 highlights the sensorial experience: "*It is quite interesting to open my eyes to this way of feeling the smells around me".* Whereas, P3 highlights the environmental experience: *"I find it interesting because with the smell we can perceive more about the environment".*

- **Innovation**

Overall, participants stressed the positive unpredictability of the experience and its potential. P7 was enthusiastic about the sensorial mapping possibility: *"I think it's a new and great idea because we can use one of our senses to describe a place for other people to be able to see it''.* P15 stated *"It's a different experience from normal to have"* and P2 concluded, *"Different, therefore calls another kind of attention that is not yet saturated"*.

- **Pitfalls**

Besides these results, one participant expressed concerns about the pitfalls of human olfactory detection:

"It is useful when there is a correlation between unpleasant smells and air pollution. It can deceive if the pollutants are not smelly" *(P5).*

This statement highlights the fact that not all molecules compositions are decoded by the human brain. To solve this problem, design solutions have eventually to involve electronic sensor technology.

7.3. Interaction model preference results

Out of total of 16 responses, one response was not valid. Results showed that seven participants (46,6%) preferred the Augmented Reality (AR) interaction model over the Virtual Reality (VR) (26,6%) (n=4). Finally, a mix of both interaction models would be preferred by four participants (26,6%).

The AR preference group emphasized positively the symbolic representation feature and the ability to complement content sections with external information sources:

"(…) With the mobile I decide how to interact and to get the info that I want and which to share. I can interact with the local "in loco". I am an agent of the planet, or of the ecology" *(P14).*

Furthermore, mobile augmented reality devices are perceived as advantageous because of its ubiquity:

"(…) I think it is a funny program and much easier to expand because it is a mobile phone application, which is a device used daily by many people" *(P6).*

The VR preference group arguments stressed the impact of transferability into remote geographic locations:

"(…) we can interact with the environment and see under what conditions it is. (...) In VR the user sees the country. In the MAR app, they don't. We have more perception on what conditions the country is in the VR experience. In the MAR app, we have not" *(P6).*

Whereas the mixed solution group accentuated the complementary of immersion and symbolic representation:

"Both - VR because it is more engaging and allows experiencing distant places; AR because it allows participation in the construction of content mapping" *(P16).*

7.4. Participants suggestions

Overall, participants suggestions englobe user experience; concept evolvement and the experience design.

- **User experience**

Two participants (12,5%) suggested improvements of the VR model in terms of immersion and user experience, associated with the early prototype phase experience.

"VR model should tie into the smelling experience for greater immersion" *(P5).*

"The VR experience could improve. There is missing support to indicate the navigation path and thus prevent accidental navigation. As you need to adapt to the navigation system, an initial guidance system should be offered" *(P1).*

- **Future concept evolvement.**

Development suggestions of the MAR model included donation feature and interactive imagery by two participants (25%) to enhance the experience:

"The MAR app could also have info about volunteering and donations for environmental causes" *(P10).*

"If the MAR app also had photos of the country, it would be more captivating" *(P9).*

Furthermore, one participant (12,5%) envisioned interactive merging modes:

"It would be interesting to merge the two interfaces. Being and seeing an image in which each place is associated with a symbol that in turn is associated with a smell" *(P8).*

- **Experience Design.**

One participant (12,5%) highlighted his positive personal sensorial experience:

"I enjoyed degustation without knowing what I was tasting" *(P12).*

Finally, three participants (18,75%) emphasized their support of the overall experience and entrepreneurship opportunity.

"It was a good experience" *(P4).*

"Go ahead" *(P15).*

"Please go on!" (P16).

7.5. Section Overview.

Having formulated our proof-of-concept assumptions we conceptualized, designed and implemented two design project that followed specific design hypotheses. The projects addressed technologies that we elected as the most adequate to fulfil the research mission: Mobile Virtual Reality (MVR) and Mobile Augmented Reality (MAR). We adapted Multisensory HCI Design methodology, investigated crossmodal correspondences and designed digital experiences that users evaluated through prototype interaction. Our final proof-of-concept evaluation proved that we were right.

8. Conclusion and Future Work

Having presented and discussed how chemical senses might be communicated and through digital experiences and how they could be included in environmental health communication strategies with virtual reality and augmented reality applications, this final part concludes my research findings. We position the work within communication and multisensory HCI design, outlining the significance of our original contributions to knowledge and pointing the limitations of the work, discussing future developments. We conclude with our vision for how chemical sense and environmental communication can benefit from the multisensory design practices of sensory communication.

In the thesis, we developed two main research questions:

RQ1. How can the chemical senses be included in digital media design?

RQ2: How can the chemical senses communicate environmental health on digital platforms?

As a design practitioner, we approached the work as research-through design, using Haverkamp's synesthetic design methodology proposal and crossmodal correspondences research to unfold data collection, conceptualization and implementation of interactive digital experiences with smell and taste.

The resulting *Earthsensum* design project offers practice-led and practice-based contributions to knowledge. The symbolic representation system for chemical senses are practice-led as their creation provided the operational knowledge for subsequent works.

The methodological approach seeks to demonstrate design considerations, suggest possible solutions and summarise interdisciplinary foundations that support their conceptualization. The practice-based works, *Earthsensum* mobile virtual reality and *Earthsensum* mobile augmented reality, contribute new perspectives into chemical sense dimensions of environmental information and significance, suggesting innovative forms for its communication and reconsideration in digital media.

In the next section, we summarise the practice and thesis in order to highlight key findings.

8.1. Findings

In Part Two we demonstrated through literature and design practice review, how environmental communication and technology has been applied for multiple purposes, yet almost invisible for the non-scientific public. Environmental health communication modes have predominately either defined by the government and political rulers or citizen-science practices and is limited to either monitoring or forecasting operations. Not so much it is framed as an elementary "mutual" human-environmental communication relationship, that a changing environment requires humans to recover, for sustainability and adaptation in this present century. While the HCI field has embraced multisensory research that explores new paradigms of smell and food interaction, we found limited contemplation and inclusion of the chemical senses within environmental communication and multisensory HCI design. This state-of-the-art led us to develop my research questions.

In Part Three, we present the *Earthsensum* design project. The two design case studies that compose it, primarily addressed the following secondary research questions:

- **R 2.1.** How can the chemical sense be applied to inform such a system?

- **R 2.2.** How is the design strategy of such Multisensory HCI Experience?

- **R 2.3.** What is the Impact of this Multisensory HCI Experience on Users?

The design process builds up along two main design phases - first, a cross-sensory analogy and symbolic construction phase, followed by a meaning and communication construction phase.

Earthsensum's first design phase offered environmental smell and taste experiences about real geolocations without contextual clues. This phase is practice-led and investigated the analogy and symbolic construction. It comprised collecting of crossmodal association data of individual chemical sense perceptions that could be applied on interaction modules.

The second design phase provided the contextualization of the experience for meaning-building. This phase **is** practice-based as we conceptualized, designed and developed interactive prototypes for proof-of-concept validation, in accordance with the chosen technologic platforms - Mobile Virtual Reality (MVR) and Mobile Augmented Reality (MAR) [49].

The types of design materials deployed in this practice research included:

Crossmodal Association

- Symbolic representation of chemical sense perceptions

Earthsensum MVR project

- Storyboard
- Information Architecture
- Functional Specifications
- 360º image collection
- Graphic UI components
- Motion Graphics
- Wireframing
- Low-Fi Prototype
- High-Fi Prototype

Earthsensum MAR project

- Sketching / Wireframes
- Information architecture
- Functional Specifications
- Visual design
- Graphic UI components
- Low-Fi Prototype
- High-Fi Prototype

***Earthsensum* Mobile Virtual Reality Project.** We explored immersive technology to provide virtual tours in environmental hazard locations related to smell or taste perceptions. By having tasted or smelled an ingredient, to which its related remote location the user is presented, we assumed the possibility to establish an association between a geographic location and the chemical senses, besides its environmental health information. This purpose required additional meaning layers that multimedia components and contents convey.

***Earthsensum* Mobile Augmented Reality Project.** We investigated how the symbolic representation system could be handled as an interface concept. In this prototype, the interaction dynamic was more explicit, as it was represented graphically after participants having manipulated them as tangible forms. We explored how augmented reality technology could allow to index smell and taste representation by geographic coordinates and link these to geo-context driven information. By these terms, we tested how chemical sense annotation facilities could relate to environmental health information.

Through practice-based investigation of multisensory HCI design practice, we demonstrated how chemical senses are powerful media to consider when designing for environmental health communication strategies addressing information, education and behaviour change.

8.1.1. Symbolic representation system.

Through the process of visualizing and handling smell and taste perceptions, we overcome barriers that limited its inclusion in digital media as also in the realm of environmental communication. The research offers insight on how to build a symbolic representation system of smell and taste perceptions in augmented and virtual reality environments. This system codes and decodes smell and taste human experiences, opening a new design direction for HCI. Ongoing efforts of cross-modal correspondences research have put some light on revealing symbolic attribution mechanisms of shape and colour to taste and smell [223], [297], [298]. These studies focus on how to predict human behaviour on domains such as consumer behaviour, among others. However, our objective is to give individuals the tools to create their unique symbolic attribution of what is perceived *in loco*.

This research shows that non-verbal communication is suitable for digital implementation. Basic geometric shapes, texture and colour schemes allow individuals to represent symbolically their smell and taste experience.

Furthermore, it revealed participants approval of the conceptual approach. During the experiment, we noted how participants reacted with strangeness when asked to profile their chemical perceptions with abstract forms. Yet throughout the association task completion, they were positively hooked by the potential of their expressive possibilities.

From anecdotal observations that should be properly followed up, we found that participants reached independently similar symbolic formulations to represent sensorial experiences. They converged to represent ammonia aggressiveness as a sharp-edged shape; hydrogen sulphide decomposition as an angular shape, and dimethyl sulphide as a round shape. Regarding flavour, near all associated spinach smooth texture to diagonal lines; soy salty ambivalence to angular and round combinations; and clove spiciness to sharp-edged shapes. Studies have shown that shape-taste associations in general combine circular forms with sweet tastes and angular forms with bitter tastes [299]. Emotion-shape associations testify that sharply angled shapes trigger negative emotions and curved shapes positive ones [300]. This research revealed that abstract formulation conventions are imbued in the cultural body as reference resources and that participants applied these resources amid of a non-conventional field. This led us to envision its system application as markers or indicators of human perceptual events.

8.1.2. Chemical sense and environmental health communication.

This research contributes to the discussion of chemical sense inclusion in environmental health communication. The senses of smell and taste are linked to the environment and consequently to human health and well-being. The most common way of environmental pollutants to enter into the human body is through breathing and ingestion. In this way, they are distributed by the bloodstream and reach organs and nervous system and may harm human health [1], [3]. In this context, this research confirms that pursuing chemical sense communication is crucial to raise awareness about these themes. Not only participants praised the opportunity of having acknowledged how their sense of smell or taste informed their every-day experience, as also they appreciated to discover how the chemical senses are blended with environmental information.

8.1.3. Multisensory HCI design framework.

The design practices created in this research uncovered new opportunities for HCI and environmental communication design aligned with “the environment – human/tech” communication relationship. We thereby proved the following:

- **Technology**

Smell and taste as communication vehicles of environmental experiences allow enhancing multidimensional environmental systems. Inclusion of the subjective dimension augments environmental interpretation as also inspires new interaction modes.

- **Cognition**

Environmental education through the chemical senses potentializes environmental awareness, as also permits recover and reinforce these sensorial faculties. Interaction paradigms should reinforce this purpose.

- **Communication**

Recognition of smell and taste as sign indices amplifies their application possibilities in environmental communication. As a cultural act, these sensory perceptions are indissociably from a geographical space, time, emotion and events, among others. These are carriers of sign systems, which depending on its construct, can frame a certain message or tell a certain story [301].

We observed two key factors that influenced our experience design: the natural environmental setting and the situational context. We evoked the natural setting by presenting smells and tastes derived from the real world. Technology mediated the situational context by communicating the environmental setting. As environmental events are bounded to time and space of occurrences, MVR experience brought closer remote events, whereas the MAR experience evidenced local events.

Our experiment design implied from the start participants engaged with smell and taste experiences, followed by the experiences with the interactive prototypes. The experiment sequence assumed that participants had to engage with their singular chemical sense perceptions, before elaborating about their environmental meaning correspondence. We observed how participants showed surprise and curiosity while they progressed along the experiment path. As attribution choices were mandatory, they ended up discovering new perspectives about their sensorial experiences. When they engaged with the prototypes, participants were already imprinted with their previous chemical sense experience and thereby more available to construct meaning through the digital content experience. This strategy may have contributed to the overall positive results.

Haverkamp stresses that "intuitive strategies based on cross-modal analogy, association and symbolism are suitable for creating a design that provides connections between the senses, which directly appear appropriate and easy to interpret" [43, p. 139]. Nevertheless, to avoid misinterpretation it is prerequisite "that associative and symbolic contents are known to the user" [43, p. 139]. This cognitive association congruency has to be consistent along the design process, considering contextual factors. Regarding our design concepts, even if smell and chemical perceptions and associations did not rely on universal assumptions, participants of the study were able to uncover their connotations and message.

8.2. Proof of concept.

Our proof-of-concept englobed the concept experience (Part three – section 5, section 6) and the concept evaluation (Part three – section 7). The overall evaluation design intended to investigate the dimensions of relevance (utility) and awareness (impact).

This research demonstrates that both digital media experiences increased chemical sense and environmental awareness. Overall, the conceptual approach of linking smell and taste to environmental events was understood and highly supported as an innovative concept for environmental health communication. Our study results revealed that linking chemical senses with environmental health benefits environmental health communication strategies.

Verbeek states that interaction design is “designing relations between humans and the world, and, ultimately designing the character of the way how we live our lives” [302, p. 31]. If we pretend to attain a more sustainable future, we have to design these desirable actions. Addressing chemical sense education first, to unfold its application possibilities, benefits Multisensory HCI design. By this means the foundations would be placed upon which its framework could expand.

Overall this research provides an original contribution to the knowledge on how to represent smell and taste in digital platforms. By this means, this research contributes to Multisensory HCI design framework evolvement. It achieves it through objective and interpretative methods, a belief in the power of design and creativity as essential demands in understanding our relationship with our changing environment. Our work aims to foster environmental awareness through chemical sense awareness.

8.3. Limitations

Limitation of this work is related to our experiment set up and the early stage of the prototypes. Despite suggesting environmental experiences through smell and taste, these were experienced in a lab environment and not in the “real world”. Regarding the digital media experiences, participants had high immersive expectations while testing our basic prototype demos, but they could not observe digital object blending with the physical world. This fact did not interfere with their prototype conceptual evaluation. However, it might influence scores like presence and satisfaction.

8.4. Future Work

The findings of this research lead us to envision the continuation of *Earthsensum* project. Further developments include:

- Research of additional formal association possibilities of our symbolic representation concept, such as combination possibilities of organic and sharp shapes and inclusion of sound.

- Bringing the experimental concept into the "real world" and investigating how chemical sense/ environmental events are perceived and mapped by this symbolic representation paradigm.

- Exploring aesthetical expression modes of this symbolic system in immersive and augmented reality platforms.

- Investigating tools for chemical sense education and environmental literacy, targeting young age groups.

- Evolving our environmental health communication strategy with multisensorial experience design.

- Building more technical refined prototypes either with Augmented Reality tools and Virtual Reality tools. In particular, we aim to explore virtual tangible sensorial communication for educational contexts.

- Testing these prototypes with a wider number and cultural variances of participants.

- Building thereby a chemical sense perception map of geo-locations and geo-events.

This thesis demonstrates how including smell and taste in digital platforms raised curiosity and motivation among young people to pursuit environmental literacy. By experiencing an otherwise volatile perception as a tangible experience, communication and sharing of those who experienced it was enabled. Knowledge building about smell and taste perceptions and its interconnection with environmental health raises reflection and fosters problem-solving. With this research, we hopefully are contributing not only to the Multisensory HCI design framework but also to a constructive environment-human-technology relationship paradigm, that the planet earth is claiming.

Tribute

R. Buckminster Fuller (1895 – 1983)
Operating Manual for Spaceship Earth, 1969

“Typical of the subsidiary problems within the whole human survival problem, whose ramifications now go beyond the prerogatives of planners and must be solved, is the problem of pollution in general-pollution not only of our air and water but also of the information stored in our brains. We will soon have to rename our planet "Poluto." In respect to our planet’s life sustaining atmosphere we find that, yes, we do have technically feasible ways of precipitating the fumes, and after this we say, "But it costs too much." There are also ways of desalinating sea water, and we say, "But it costs too much." This too narrow treatment of the problem never faces the inexorably-evolving and solution-insistent problem of what it will cost when we don’t have the air and water with which to survive” [303, p. 24].

“I now go on to speculate that I think that what we all really mean by wealth is as follows: "Wealth is our organized capability to cope effectively with the environment in sustaining our healthy regeneration and decreasing both the physical and metaphysical restrictions of the forward days of our lives” [303, p. 27].

“It is obvious that the real wealth of life aboard our planet is a forwardly-operative, metabolic, and intellectual regenerating system. Quite clearly, we have vast amounts of income wealth as Sun radiation and Moon gravity to implement our forward success. Wherefore living only on our energy savings by burning up the fossil fuels which took billions of years to impound from the Sun or living on our capital by burning up our Earth’s atoms is lethally ignorant and also utterly irresponsible to our coming generations and their forward days. Our children and their children are our future days. If we do not comprehend and realize our potential ability to support all life forever we are cosmicly bankrupt” [303, p. 28].

Donella Meadows (1941 – 2001)
Limits to Growth - The 30-Year Update, 2004

"(…) The depths of human ignorance are much more profound than most of us are willing to admit. This is especially so at a time when the global economy is coming together as a more integrated whole than it has ever been, when that economy is pressing against the limits of a wondrously complex planet, and when wholly new ways of thinking are called for" [12, p. 280].

"(…) It is not easy to practice love, friendship, generosity, understanding, or solidarity within a system whose rules, goals and information streams are geared for lesser human qualities. But we try, and we urge you to try. Be patient with yourself and others as you and they confront the difficulty of a changing world. Understand and empathize with inevitable resistance; there is resistance, some clinging to the ways of unsustainability, within each of us. Listen to the cynicism around you and have compassion for those who believe in it., but don't believe it yourself.

Humanity cannot triumph in the adventure of reducing the human foot-print to a sustainable level if that adventure is not undertaken in a spirit of global partnership. Collapse cannot be avoided if people do not learn to view themselves and others as part of one integrated global society. Both will require compassion, not only with the here and now, but with the distant and future as well. Humanity must learn to love the idea of leaving future generations a living planet" [12, p. 282].

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Appendix A

Evaluation Methodology

A 1. Survey - Smell experience

Earthsensum - Survey - Smell - Google Forms

Earthsensum

Hello! Thank you for participating in this research! Who are you?
* Required

1. Email address *

2. Which category below includes your age?

Mark only one oval.

- 17 or younger
- 18-20
- 21-29
- 30-39
- 40-49
- 50-59
- 60 or older

3. What is your gender?

Mark only one oval.

- Female
- Male
- Other

4. What is your Education?

Mark only one oval.

- Phd
- Masters
- Bachelor
- Secondary

5. What is your Area of Expertise?

6. Do you consider yourself environmentally conscious?

Mark only one oval.

	1	2	3	4	5	
Strongly Disagree						Strongly Agree

7. How does it influence your daily life?

8. Do you access environmental information?

Mark only one oval per row.

	Daily	Weekly	Monthly	Sometimes	Never
Frequency	⬭	⬭	⬭	⬭	⬭

9. Are you satisfied with the information you get?

10. Does the information content influence your behavior?

11. What is your expectation about the impact of your behavior on your environment?

Earthsensum

Exploring Chemical Senses with Multisensory HCI Design for Environmental Health Communication

A - Smell Stimuli Evaluation

Describe your Smell Perception:

12. A1. Color

What color has this smell for you?

Mark only one oval per row.

	Purple	Orange	Green	Blue
Smell A	⬭	⬭	⬭	⬭
Smell B	⬭	⬭	⬭	⬭
Smell C	⬭	⬭	⬭	⬭

13. A2. Texture

What texture has this smell for you?

Mark only one oval per row.

	Zigzag	Wave	Diagonal	Circle
Smell A	⬭	⬭	⬭	⬭
Smell B	⬭	⬭	⬭	⬭
Smell C	⬭	⬭	⬭	⬭

14. A3. Shape

What basic geometric shape has this smell for you?

	Square	Triangle	Circle
Smell A	◯	◯	◯
Smell B	◯	◯	◯
Smell C	◯	◯	◯

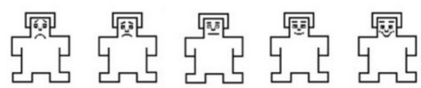
15. A4. Pleasantness

Did you like the smell?

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Smell A	◯	◯	◯	◯	◯
Smell B	◯	◯	◯	◯	◯
Smell C	◯	◯	◯	◯	◯

16. A5. Valence

How does this smell make you feel?

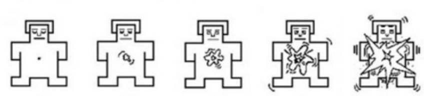


1 2 3 4 5

	Sad	Unsatisfied	Neutral	Pleased	Happy
Smell A	◯	◯	◯	◯	◯
Smell B	◯	◯	◯	◯	◯
Smell C	◯	◯	◯	◯	◯

17. A6. Arousal

What impact has this smell on you?



1 2 3 4 5

	Calm	Wide-awake	Neutral	Dull	Excited
Smell A	◯	◯	◯	◯	◯
Smell B	◯	◯	◯	◯	◯
Smell C	◯	◯	◯	◯	◯

22. A9. What is the category of this smell?

	Smell A	Smell B	Smell C
Bakery			
Sweet			
Fruit			
Fish			
Garlic			
Spices			
Cold			
Sour			
Burnt			
Acid			
Warm			
Musky			
Sweaty			
Ammonia/ruinous			
Decayed			
Wood			
Grass			
Flower			
Chemical			

23. A10. What is the affective description of this smell?

	Smell A	Smell B	Smell C
Agreeable			
Aromatic			
Bad			
Characteristic			
Delicate			
Delicious			
Delightful			
Disgusting			
Distinct			
Empyreumatic			
Evil			
Exquisite			
Faint			
Fresh			
Grateful			
Heavy Nasty			
Nauseous			

Nauseous	◯	◯	◯
Offensive	◯	◯	◯
Peculiar	◯	◯	◯
Penetrating	◯	◯	◯
Pleasant	◯	◯	◯
Powerful	◯	◯	◯
Pungent	◯	◯	◯
Rich	◯	◯	◯
Sickening	◯	◯	◯
Strange	◯	◯	◯
Strong	◯	◯	◯
Suffocating	◯	◯	◯
Unpleasant	◯	◯	◯

Description Preference Evaluation

24. A11. Which method do you prefer to describe your smell experience?

- ◯ With my own words
- ◯ From a predefined list
- ◯ Both

B - Virtual Reality Experience Evaluation

Walkthrough method for evaluating virtual reality (VR) user interfaces

25. Level of experience

	Answer
I have never used an VR App	☐
I have used an VR App several times	☐
I use VR App's on a regular basis	☐

B1 - Navigation

Task: You pass by a location. On spot you a smell a scent. You want to know more about that smell

26. B1a. Do you know where to start looking?

	1	2	3	4	5	
At no time	◯	◯	◯	◯	◯	Almost all the time

27. B1b. Can the user determine a pathway towards the target?

	1	2	3	4	5	
Difficult	◯	◯	◯	◯	◯	Easily

28. B1c. Can the user execute movement and navigation actions?

	1	2	3	4	5	
Difficult	◯	◯	◯	◯	◯	Easily

29. B1d. Can the user recognise the navigation targets ?

	1	2	3	4	5	
Difficult	◯	◯	◯	◯	◯	Easily

B2. Presence

30. B2a. How natural did your interactions with the environment seem?

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Natural

31. B2b. How completely were all of your senses engaged?

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Completely

32. B2c. How much did the visual aspects of the environment involve you?

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Very much

34. B2e. When watching the places, I had a sense of "being there".

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Very much

35. B2f. I felt I was visiting the places in the scenes.

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Very much

36. B2g. I had a sense of being together with the objects in the scenes.

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Very much

37. B3. Motion Sickness

	Answer
I felt dizzy looking at the screen	☐
My eyes felt diplopia (double vision)	☐
I felt Blurred Vision	☐
I had a headache	☐

B4. Emotional Engagement

	1	2	3	4	5	
Strongly Desagree	◯	◯	◯	◯	◯	Strongly Agree

39. B4b. Experiencing the scenes was pleasant.

	1	2	3	4	5	
Strongly Desagree	◯	◯	◯	◯	◯	Strongly Agree

40. B4c. Experiencing the scenes was interesting.

	1	2	3	4	5	
Strongly Desagree	◯	◯	◯	◯	◯	Strongly Agree

41. B4d. Experiencing the scenes was fun.

	1	2	3	4	5	
Strongly Desagree	◯	◯	◯	◯	◯	Strongly Agree

B5 - Content Exploration

42. B5a.The contents are comprehensible.

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Very much

43. B5b.The message is clear.

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Very much

44. B5c. I learned something new.

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Very much

45. B5d. I consider this content experience useful.

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Very much

46. B5e. I would recommend this experience as an education tool.

	1	2	3	4	5	
Strongly Desagree	◯	◯	◯	◯	◯	Strongly Agree

B6 - Awareness

47. B6a. Experiencing this content makes me improves my awareness about my environment.

	1	2	3	4	5	
Strongly Desagree	◯	◯	◯	◯	◯	Strongly Agree

48. B6b. Experiencing this content makes me thing about my behavior towards my environment.

	1	2	3	4	5	
Strongly Desagree	◯	◯	◯	◯	◯	Strongly Agree

49. B6c. Experiencing this content inspires me to take positive action towards my environment.

	1	2	3	4	5	
Strongly Desagree	◯	◯	◯	◯	◯	Strongly Agree

Open-response questions

Suggestions

50. B7a. What did you liked most?

51. B7b. What could be improved?

36. B2g. I had a sense of being together with the objects in the scenes.

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Very much

37. B3. Motion Sickness

	Answer
I felt dizzy looking at the screen	☐
My eyes felt diplopia (double vision)	☐
I felt Blurred Vision	☐
I had a headache	☐

B4. Emotional Engagement

	1	2	3	4	5	
Strongly Desagree	◯	◯	◯	◯	◯	Strongly Agree

39. B4b. Experiencing the scenes was pleasant.

	1	2	3	4	5	
Strongly Desagree	◯	◯	◯	◯	◯	Strongly Agree

40. B4c. Experiencing the scenes was interesting.

	1	2	3	4	5	
Strongly Desagree	◯	◯	◯	◯	◯	Strongly Agree

41. B4d. Experiencing the scenes was fun.

	1	2	3	4	5	
Strongly Desagree	◯	◯	◯	◯	◯	Strongly Agree

B5 - Content Exploration

42. B5a.The contents are comprehensible.

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Very much

43. B5b.The message is clear.

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Very much

59. C4b. I would recommend this app as an education tool.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

C5. Satisfaction

61. C5a. I enjoyed the content experience.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

62. C5b. What did you liked most?

63. C5c. What could be improved?

D - Concept Baseline Evaluation

64. D1 - What do you thing about communicating environmental health through Smell perception?

65. D2 - Which of the proposed interaction models would you prefer?

66. D3 - Do you have other comments?

Thank You!

67. Name

A 2. Survey - Taste experience

Earthsensum

Hello! Thank you for participating in this research! Who are you?

* Required

1. Email address *

2. Which category below includes your age?

   Mark only one oval.

   - 17 or younger
   - 18-20
   - 21-29
   - 30-39
   - 40-49
   - 50-59
   - 60 or older

3. What is your gender?

   Mark only one oval.

   - Female
   - Male
   - Other

4. What is your Education?

   Mark only one oval.

   - Phd
   - Masters
   - Bachelor
   - Secondary

5. What is your Area of Expertise?

6. Do you consider yourself environmentally conscious?

	1	2	3	4	5	
Strongly Disagree						Strongly Agree

7. How does it influence your daily life?

8. Do you access environmental information?

	Daily	Weekly	Monthly	Sometimes	Never
Frequency					

9. Are you satisfied with the information you get?

10. Does the information content influence your behavior?

11. What is your expectation about the impact of your behavior on your environment?

Earthsensum

Exploring Chemical Senses with Multisensory HCI Design for Environmental Health Communication

A - Taste Stimuli Evaluation

Describe your Taste Perception:

12. A1. Color

What color has this taste for you?

	Purple	Orange	Green	Blue
Taste A				
Taste B				
Taste C				

13. A2. Texture

What texture has this taste for you?

	Zigzag	Wave	Diagonal	Circle
Taste A				
Taste B				
Taste C				

14. A3. Shape

What texture has this taste for you?

	Square	Triangle	Circle
Taste A			
Taste B			
Taste C			

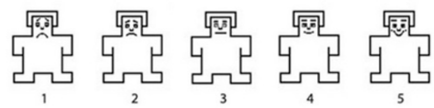
15. **A4. Pleasantness**

Did you like the Taste?

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Taste A	◯	◯	◯	◯	◯
Taste B	◯	◯	◯	◯	◯
Taste C	◯	◯	◯	◯	◯

16. **A5. Valence**

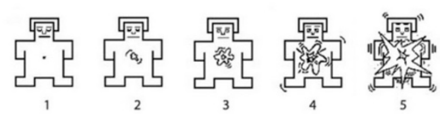
How does this Taste make you feel?



	Sad	Unsatisfied	Neutral	Pleased	Happy
Taste A	◯	◯	◯	◯	◯
Taste B	◯	◯	◯	◯	◯
Taste C	◯	◯	◯	◯	◯

17. **A6. Arousal**

What impact has this Taste on you?



	Calm	Wide-awake	Neutral	Dull	Excited
Taste A	◯	◯	◯	◯	◯
Taste B	◯	◯	◯	◯	◯
Taste C	◯	◯	◯	◯	◯

Taste Stimuli Description

Describe your Taste Experience briefly with your own words, thoughts or metaphors.

18. **A7a. How do you describe Taste A?**

19. **A7b. How do you describe Taste B?**

20. **A7c. How do you describe Taste C?**

Taste Stimuli Descriptors

Label your Taste Experience in terms of source, category and affect.

21. A8. What is the source of this Taste?

Mark only one oval per row.

	Taste A	Taste B	Taste C
Fruits	⬭	⬭	⬭
Leaves	⬭	⬭	⬭
Root	⬭	⬭	⬭
Seeds	⬭	⬭	⬭
Legume	⬭	⬭	⬭
Whole Grain	⬭	⬭	⬭
Meat	⬭	⬭	⬭
Poultry	⬭	⬭	⬭
Seafood	⬭	⬭	⬭
Dairy Products	⬭	⬭	⬭
Spice	⬭	⬭	⬭

22. A9. What is the category of this Taste?

	Taste A	Taste B	Taste C
Bitter	⬭	⬭	⬭
Sweet	⬭	⬭	⬭
Dry	⬭	⬭	⬭
Moist	⬭	⬭	⬭
Bland	⬭	⬭	⬭
Spicy	⬭	⬭	⬭
Savoury	⬭	⬭	⬭
Rich	⬭	⬭	⬭
Salty	⬭	⬭	⬭
Tasty	⬭	⬭	⬭
Sugary	⬭	⬭	⬭
Greasy	⬭	⬭	⬭
Scrumptious	⬭	⬭	⬭
Sour	⬭	⬭	⬭
Piping hot	⬭	⬭	⬭
Crunchy	⬭	⬭	⬭

23. A10. What is the affective description of this Taste?

	Taste A	Taste B	Taste C
Amazing			
Appealing			
Appetizing			
Delectable			
Delicious			
Delightful			
Divine			
Enjoyable			
Enticing			
Excellent			
Exquisite			
Extraordinary			
Fantastic			
Finger			
Licking			
Heavenly			
Lip Smacking			
Luscious			
Marvelous			
Mouthwatering			
Palatable			
Pleasant			
Pleasing			
Satisfying			
Scrumptious			
Superb			
Tantalizing			
Tasty			
Terrific			
Wonderful			
Yummi			
Disgusting			
Strange			
Unpleasant			

Description Preference Evaluation

24. A11. Which method do you prefer to describe your taste experience?

Mark only one oval.

- With my own words
- From a predefined list
- Both

B - Virtual Reality Experience Evaluation

Walkthrough method for evaluating virtual reality (VR) user interfaces

25. Level of experience

	Answer
I have never used an VR App	☐
I have used an VR App several times	☐
I use VR App's on a regular basis	☐

B1 - Navigation

Task: You pass by a streetfood market. You a taste an ingredient. You want to know more about that taste.

26. B1a. Do you know where to start looking?

	1	2	3	4	5	
At no time	◯	◯	◯	◯	◯	Almost all the time

27. B1b. Can the user determine a pathway towards the target?

	1	2	3	4	5	
Difficult	◯	◯	◯	◯	◯	Easily

28. B1c. Can the user execute movement and navigation actions?

	1	2	3	4	5	
Difficult	◯	◯	◯	◯	◯	Easily

29. B1d. Can the user recognise the navigation targets ?

	1	2	3	4	5	
Difficult	◯	◯	◯	◯	◯	Easily

B2. Presence

30. B2a. How natural did your interactions with the environment seem?

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Natural

31. B2b. How completely were all of your senses engaged?

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Completely

32. B2c. How much did the visual aspects of the environment involve you?

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Very much

33. B2d. How much did the auditory aspects of the environment involve you?

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Very much

34. B2e. When watching the places, I had a sense of "being there".

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Very much

35. B2f. I felt I was visiting the places in the scenes.

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Very much

36. B2g. I had a sense of being together with the objects in the scenes.

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Very much

37. B3. Motion Sickness

	Answer
I felt dizzy looking at the screen	☐
My eyes felt diplopia (double vision)	☐
I felt Blurred Vision	☐
I had a headache	☐

B4. Emotional Engagement

38. B4a. Experiencing the scenes was enjoyable.

	1	2	3	4	5	
Strongly Desagree	◯	◯	◯	◯	◯	Strongly Agree

39. B4b. Experiencing the scenes was pleasant.

	1	2	3	4	5	
Strongly Desagree	◯	◯	◯	◯	◯	Strongly Agree

40. B4c. Experiencing the scenes was interesting.

	1	2	3	4	5	
Strongly Desagree	◯	◯	◯	◯	◯	Strongly Agree

41. B4d. Experiencing the scenes was fun.

	1	2	3	4	5	
Strongly Desagree	◯	◯	◯	◯	◯	Strongly Agree

B5 - Content Exploration

42. B5a.The contents are comprehensible.

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Very much

43. B5b.The message is clear.

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Very much

44. B5c. I learned something new.

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Very much

45. B5d. I consider this content experience useful.

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	Very much

46. B5e. I would recommend this experience as an education tool.

	1	2	3	4	5	
Strongly Desagree	◯	◯	◯	◯	◯	Strongly Agree

50. B7a. What did you liked most?

51. B7b. What could be improved?

C - Augmented Reality Concept Experience Evaluation

52. Level of experience

Mark only one oval per row.

	Answer
I have never used an AR App	◯
I have used an AR App several times	◯
I use AR App's on a regular basis	◯

C1. Ease of Use

Task #1- You perceive a certain Taste in your environment. You want to label this Taste and share this experience.

Task #2 - You want to find out more about this kind of Taste.

Task #3 - You would like to have a more participative attitude towards your environment. You want to know how to take action.

C2. Ease of Learning

53. Where the navigation commands easy to remember?

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

C3. Relevancy

54. C3a.I am now more aware about my sense of taste.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

55. C3b.This taste annotation system enables me to express my taste experience.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

56. C3c. This taste annotation system increases my environmental awareness.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

C4. Usefulness

57. C4a. I consider this app experience useful.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

58. Why?

59. C4b. I would recommend this app as an education tool.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

60. Why?

C5. Satisfaction

61. C5a. I enjoyed the content experience.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

62. C5b. What did you liked most?

63. C5c. What could be improved?

D - Concept Baseline Evaluation

64. D1 - What do you thing about communicating environmental health through taste perception?

65. D2 - Which of the proposed interaction models would you prefer?

66. D3 - Do you have other comments?

Thank You!

67. Name

A 3. Descriptor List - Smell

EARTHSENSUM
SMELL STIMULI EVALUATION

Name

A8 - Smell Source List:

	Animals
	Cleaning
	Coffee
	Complex
	Construction
	Emissions
	Food/ Beverage
	Humans
	Industrial
	Nature
	Non-Food
	Smoke
	Subway
	Synthetic Fragrance
	Tobacco
	Waste

A9 - Smell Categories List:

	Acid
	Ammonia/Ruinous
	Bakery
	Burnt
	Chemical
	Cold
	Decayed
	Fish
	Flower
	Fruit
	Garlic
	Grass
	Musky
	Sour
	Spices
	Sweaty
	Sweet
	Warm
	Wood

A10 - Smell Affective description List:

	Agreeable
	Aromatic
	Bad
	Characteristic
	Delicate
	Delicious
	Delightful
	Disgusting
	Distinct
	Empyreumatic
	Evil
	Exquisite
	Faint
	Fresh
	Grateful
	Heavy Nasty
	Nauseous
	Offensive
	Peculiar
	Penetrating
	Pleasant
	Powerful
	Pungent
	Rich
	Sickening
	Strange
	Strong
	Suffocating
	Unpleasant

A 4. Descriptor List - Taste

EARTHSENSUM
TASTE STIMULI EVALUATION

Name

A8 – Taste Source List:

	Dairy Products
	Fruits
	Leaves
	Legume
	Meat
	Poultry
	Root
	Seafood
	Seeds
	Spice
	Whole Grain

A9 – Taste Categories List:

	Bitter
	Bland
	Crunchy
	Dry
	Greasy
	Moist
	Piping hot
	Rich
	Salty
	Savoury
	Scrumptious
	Sour
	Spicy
	Sugary
	Sweet
	Tasty

A10 - Taste Affective description List:

	Amazing
	Appealing
	Appetizing
	Delectable
	Delicious
	Delightful
	Disgusting
	Divine
	Enjoyable
	Enticing
	Excellent
	Exquisite
	Extraordinary
	Fantastic
	Finger
	Heavenly
	Licking
	Lip Smacking
	Luscious
	Marvellous
	Mouth-watering
	Palatable
	Pleasant
	Pleasing
	Satisfying
	Scrumptious
	Strange
	Superb
	Tantalizing
	Tasty
	Terrific
	Unpleasant
	Wonderful
	Yummy

A 5. Virtual Reality UX Evaluation Sheet

EARTHSENSUM
Record Sheet for the Observer
Virtual Reality (VR) user interface evaluation

Name

Walkthrough method

Action	***Question***	***Observation***
1. Find path to target	(i) Does the user know where to start looking?	
2. Decide direction	ii) Can the user determine a pathway towards the target?	
3.Move Navigate	(iii) Can the user execute movement and navigation actions?	
4. Interpret change	(iv) Can the user recognise the search target?	

A 6. Augmented Reality UX Evaluation Sheet

EARTHSENSUM
Record Sheet for the Observer
Augmented Reality (AR) user interface evaluation

Name

Task Description	
Duration How many seconds did the user took complete?	
Expected Path Has followed the expected path?	
(Expected Path)	
Reaction What where the user's expression and comments?	
Errors How many clicks in the wrong places?	
User is Lost What did the user expect the app would do?	
Notes	

Appendix B

Complementary Evaluation Data

B 1. Haptic and Graphic association: quantitative data report

Table 10 - Haptic association attribution of smell and taste experiences evaluated by 8 participants (100%) of each group.

Variables		**Smell A (Ammonia)**	**Smell B (Hydrogen Sulfide)**	**Smell C (Dimethyl Sulfide)**	**Taste A (Spinach)**	**Taste B (Soy)**	**Taste C (Clove)**
		%	%	%	%	%	%
Shape	Cube	12,5%	75%	12,5%	37,5%	50%	12,5%
	Tennis Ball	12,5%	12,5%	62,5%	62,5%	25%	0
	Trigger Ball	75%	12,5%	25%	0	25%	87,5%
Texture	Denim	25%	75%	0	62,5%	37,5%	0
	Sandpaper	75%	25%	0	0	12,5%	87,5%
	Velvet	0	0	100%	37,5%	50%	12,5%

Table 11 - Graphic association attribution of smell and taste experiences evaluated by 8 participants (100%) for each group

Variables		**Smell A (Ammonia)**	**Smell B (Hydrogen Sulfide)**	**Smell C (Dimethyl Sulfide)**	**Taste A (Spinach)**	**Taste B (Soy)**	**Taste C (Clove)**
		%	%	%	%	%	%
Color	Purple	50%	37,5%	0	5%	25%	25%
	Orange	25%	25%	0	0	12,5%	75%
	Green	12,5%	25%	37,5%	62,5%	12,5%	0
	Blue	12,5%	12,5%	62,5%	12,5%	50%	0
Texture	Zigzag	62,5%	25%	0	0	12,5%	75%
	Wave	12,5%	62,5%	12,5%	12,5%	37,5%	12,5%
	Diagonal	12,5%	12,5%	37,5%	87,5%	0	0
	Circles	12,5%	0	50%	0	50%	0
Shape	Square	12,5%	87,5%	0	25%	62,5%	12,5%
	Triangle	75%	0	25%	37,5%	12,5%	50%
	Circle	12,5%	12,5%	75%	37,5%	25%	37,5%

B 2. Smell association data overview

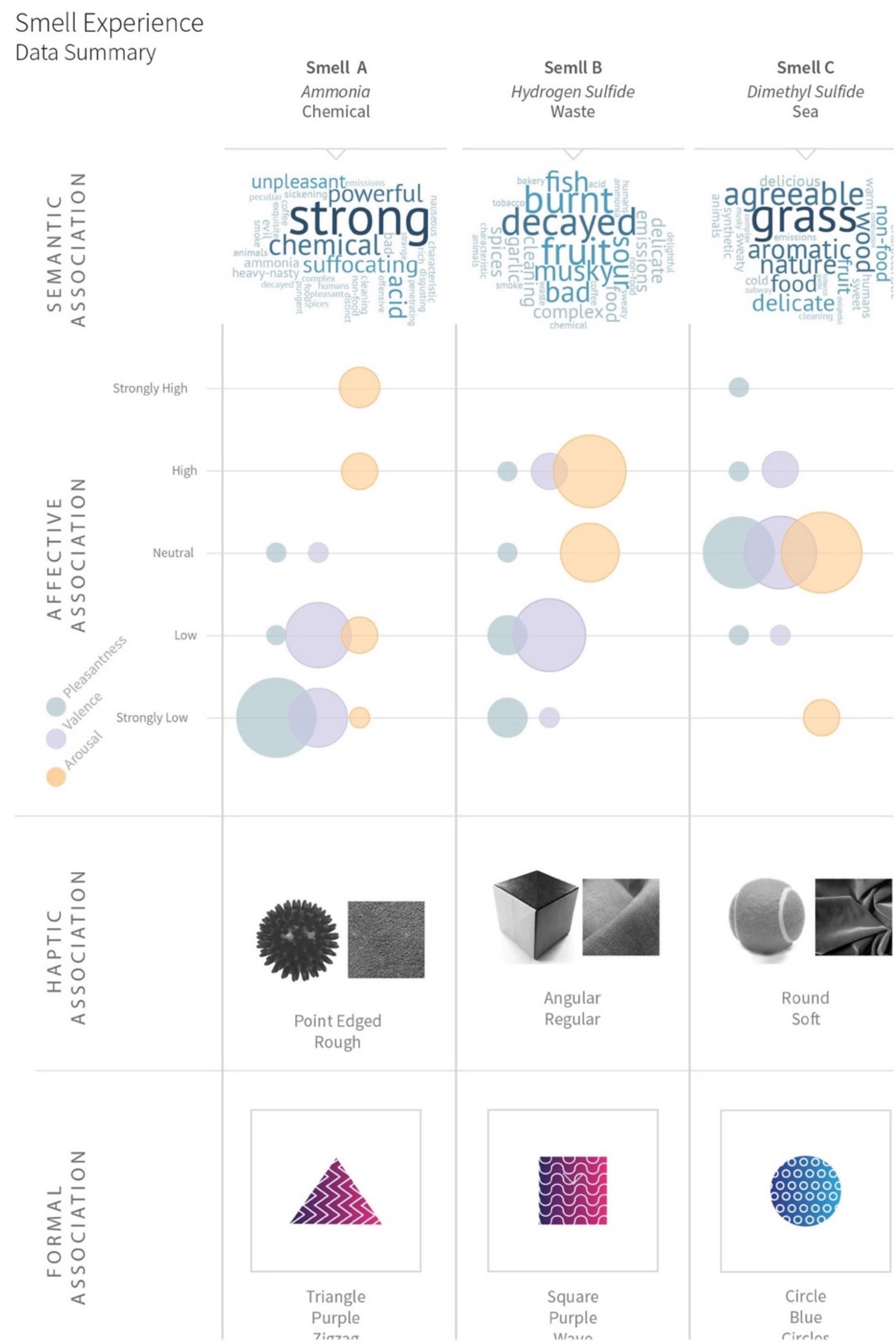


Figure 41 - Smell association summary (Participants: n=8).

B 3. Taste association data overview

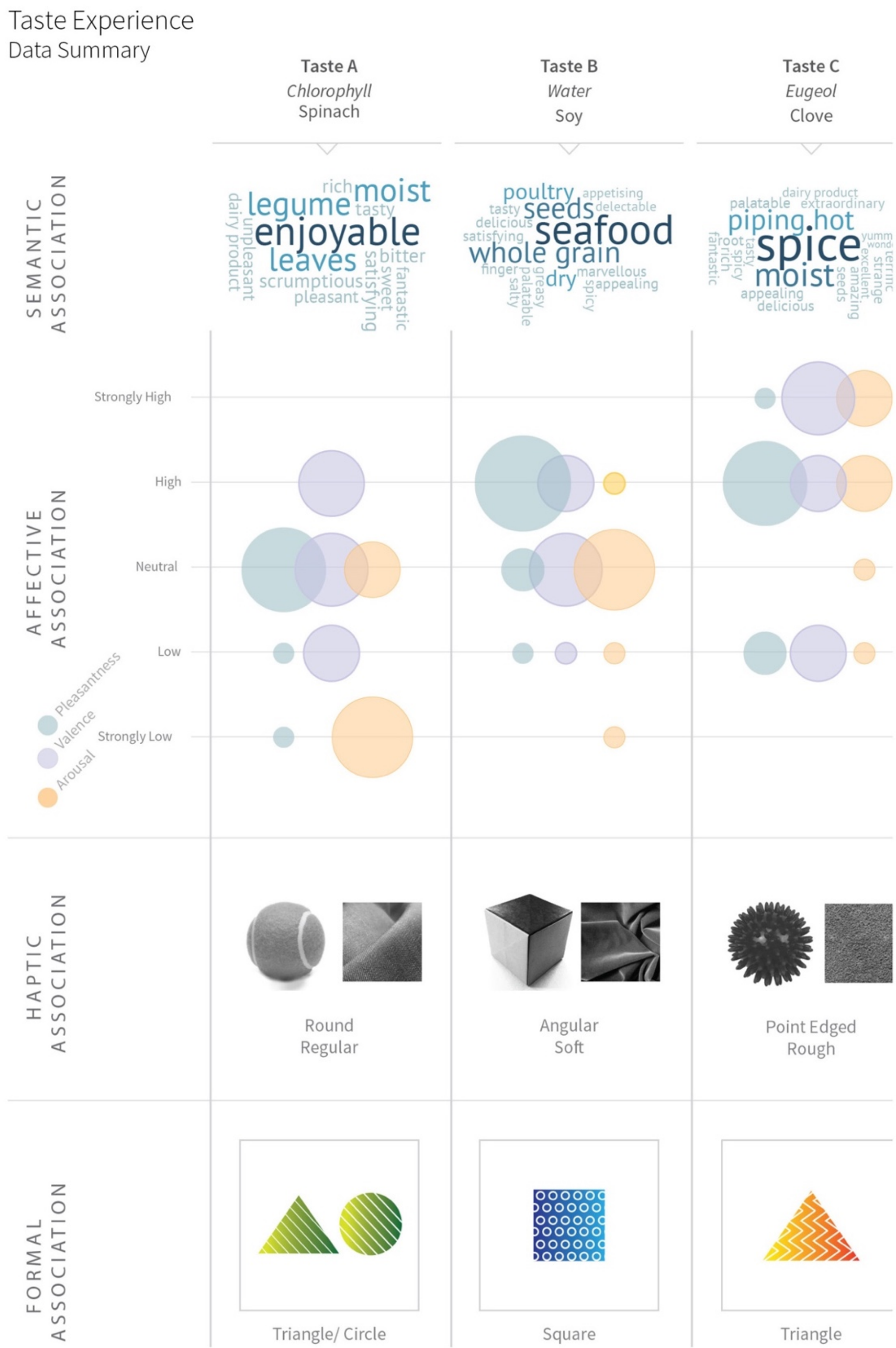
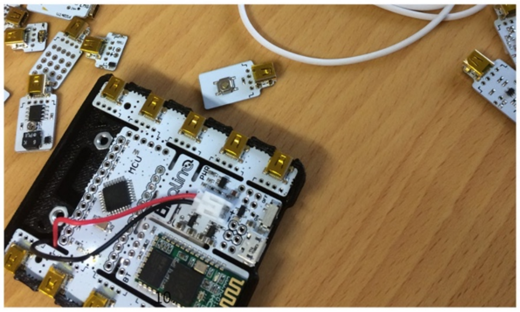


Figure 42 - Taste association summary (Participants: n=8).

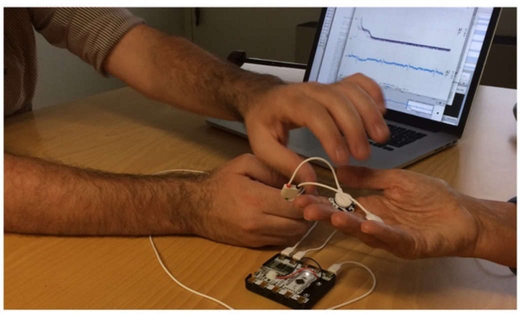
Appendix C
Pre-Study Experiment

Pre-study Experiment
Smell biofeedback with
BITalino (r)evolution Plugged Kit BT



Experiment

Date: 2017-11-06
Local: Instituto Superior Técnico Lisboa
Responsible: Professor Hugo Silva and Paula Neves
Participant Volunteer: Woman, Age 56



Objective

We aimed to test smell bio-feedback with aN Electrodermal activity (EDA) sensor that BITalino provides. We wanted to investigate how several smell reactions would be represented by the system, and if these would be relevant for our study.

Procedure

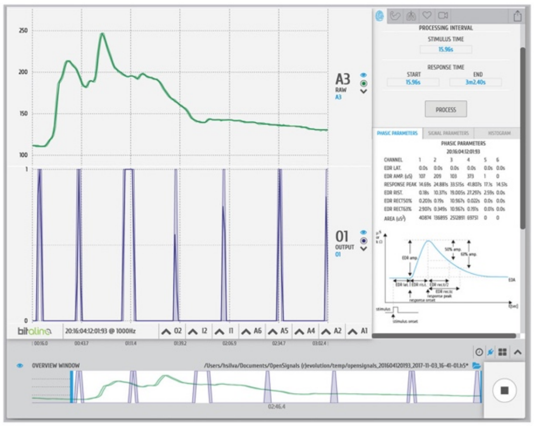
The sensors were placed on the body and calibrated with the software. A marker (button signal) was programmed to distinguish smell data acquisition.

Smell Stimuli

Smell samples were presented in transparent odourless plastic boxes.
Smell stimuli were selected by known familiar scents: Coffee; Balsamic vinegar; Pine Essential Oil and Bleach.

Figure 43 - Pre-Study Experiment with BITalino

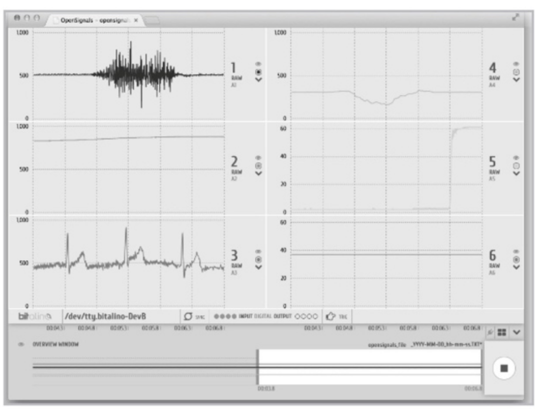
Pre-study Experiment
Smell biofeedback with
BITalino (r)evolution Plugged Kit BT



Results

The graph record presents the electrodermal response to one smell.
The volunteer comments while smelling, switched between guessing the smell source and evaluating its pleasantness.
The electrodermal graph shows an initial high pitch and intensity slowing down of the smell experiment.

When confronted with a non-identified smell the volunteer referred a mental image: "Horrible smell! It smells like old tobacco cigarettes, like when you leave cigarette beateas in a closed room and the next day you enter in that room."



Conclusion

We expected that the three electrodermal reactions would be visualized as three overlapping graphs. By these terms, we hoped to achieve a biodata profile of smell and taste samples. However, at the time of the experiment, the system would not deliver this functionality. This could only be achieved involving third-party tools and developers.

We also observed that talking and sharing information while smelling, influences the electrodermal results. We induced that to perform such a test, participants had to be silent and have a neutral environment.

We acknowledged the broad possibilities that BITalino offers to design different biosignals acquisition experiments. Yet, we concluded that regarding our study mission, biodata was not fundamental.

Figure 44 – Screengrabs of BITalino's data visualization features.

Appendix D
Design Project Details

D 1. Visual Identity development

Brand Identity

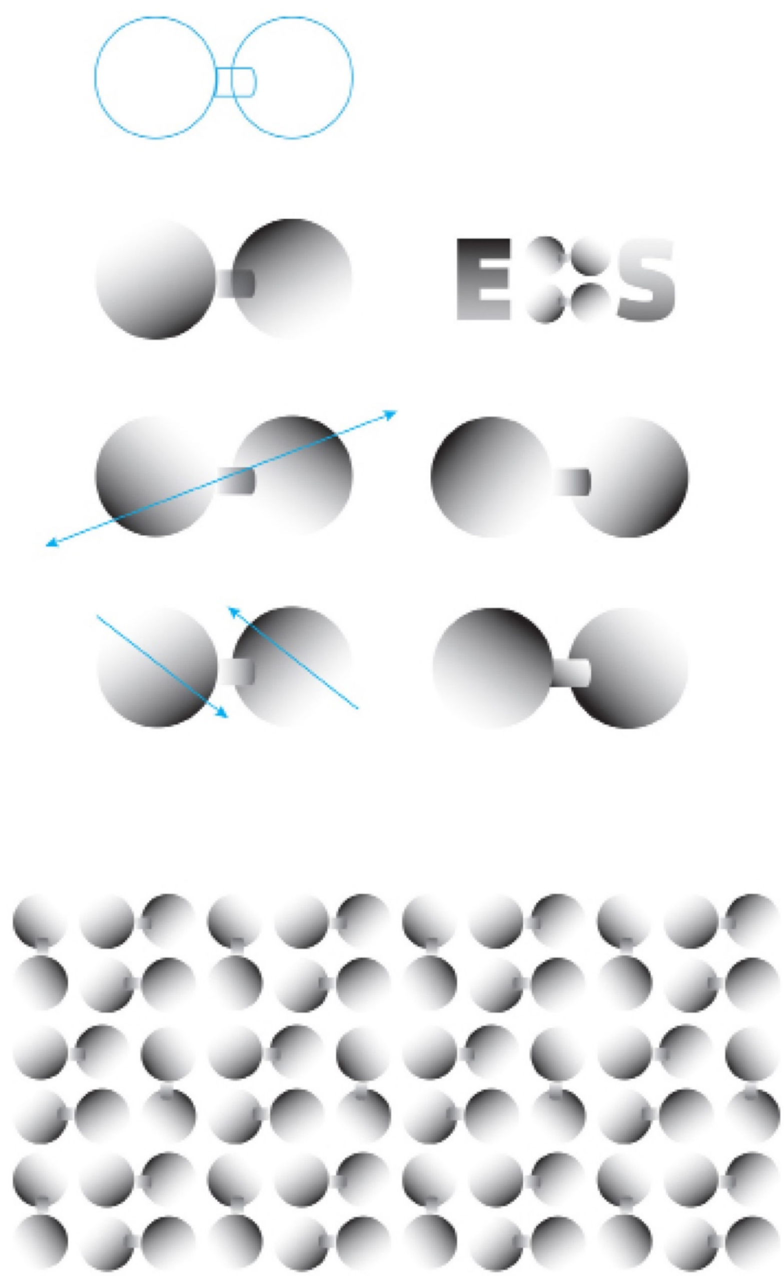


Figure 45 - Brand Design development: Symbol.
It’s shape and composition represents molecular compositions.

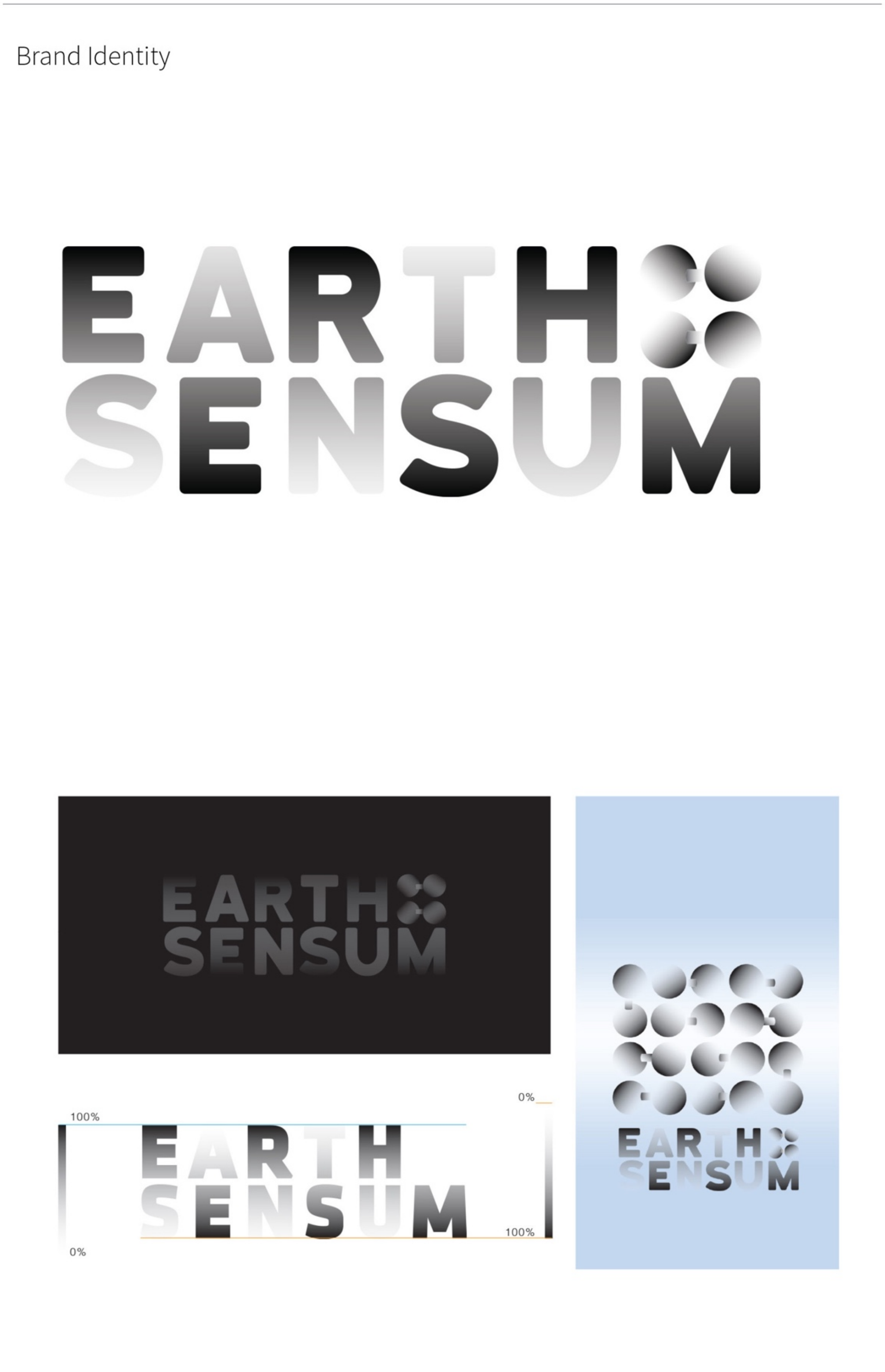


Figure 46 - Brand Design development: Logo.
Typographic treatment aims to express the visible and invisible layers of information that surrounds our body and stimulates our sensory perception.

D 2. Mobile Virtual Reality design project

D 2.1. Organising and structuring: Information Architecture

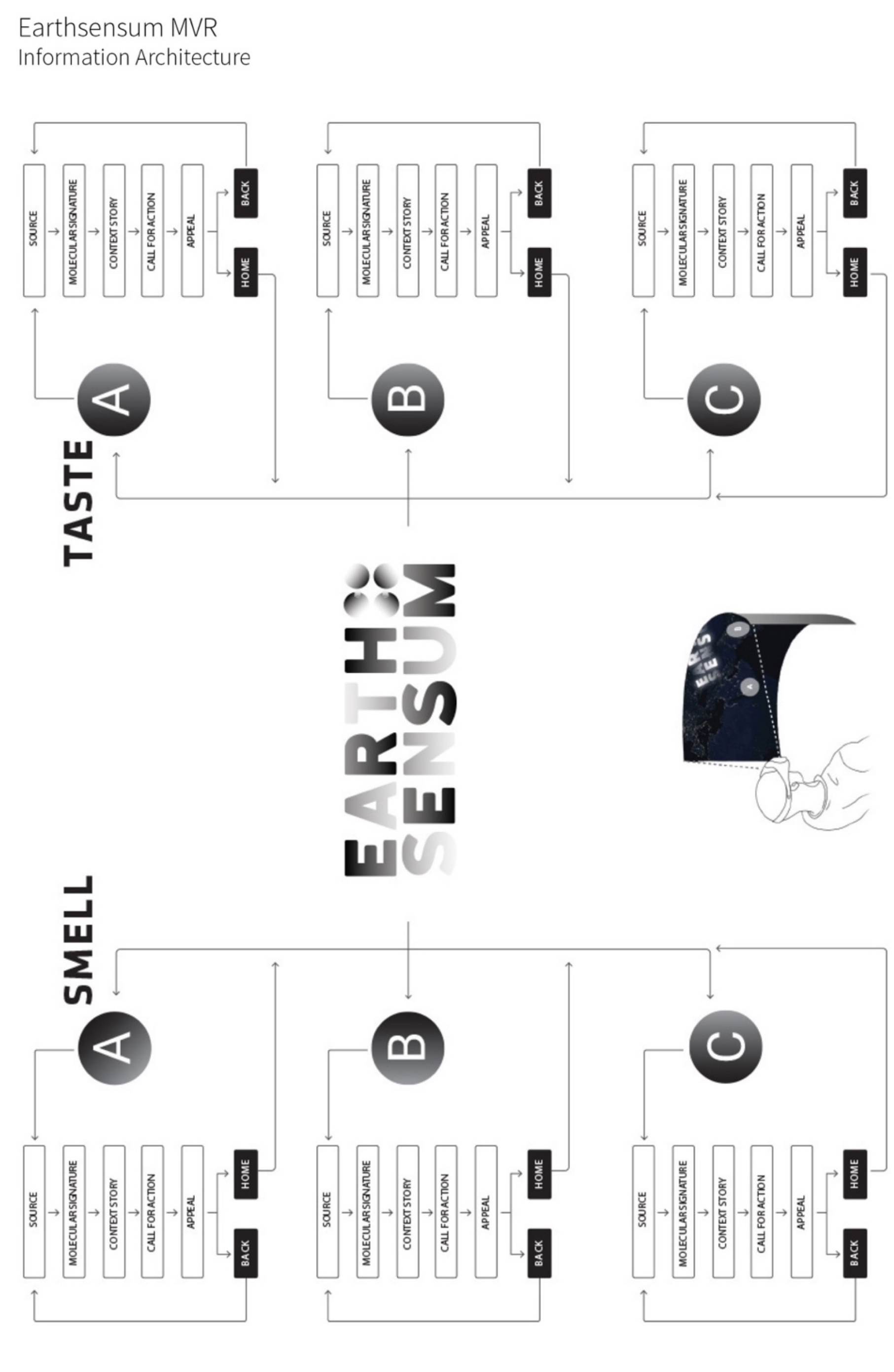


Figure 47 - Earthsensum MVR Information Architecture.

D 2.2. Production: Interface design and 3d models

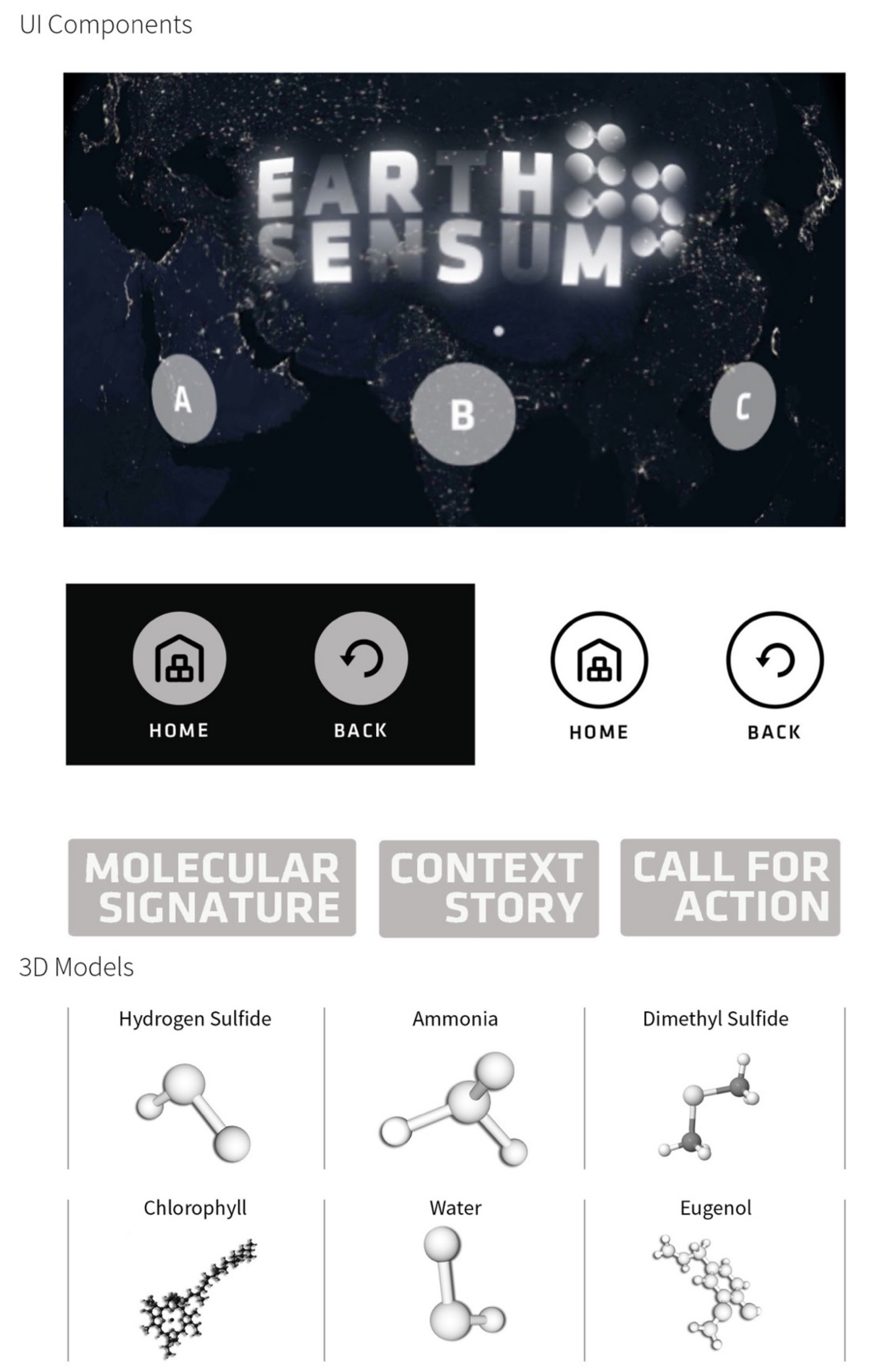


Figure 48 - UI components design and 3d molecules models.

D 2.3. Production: Animation design

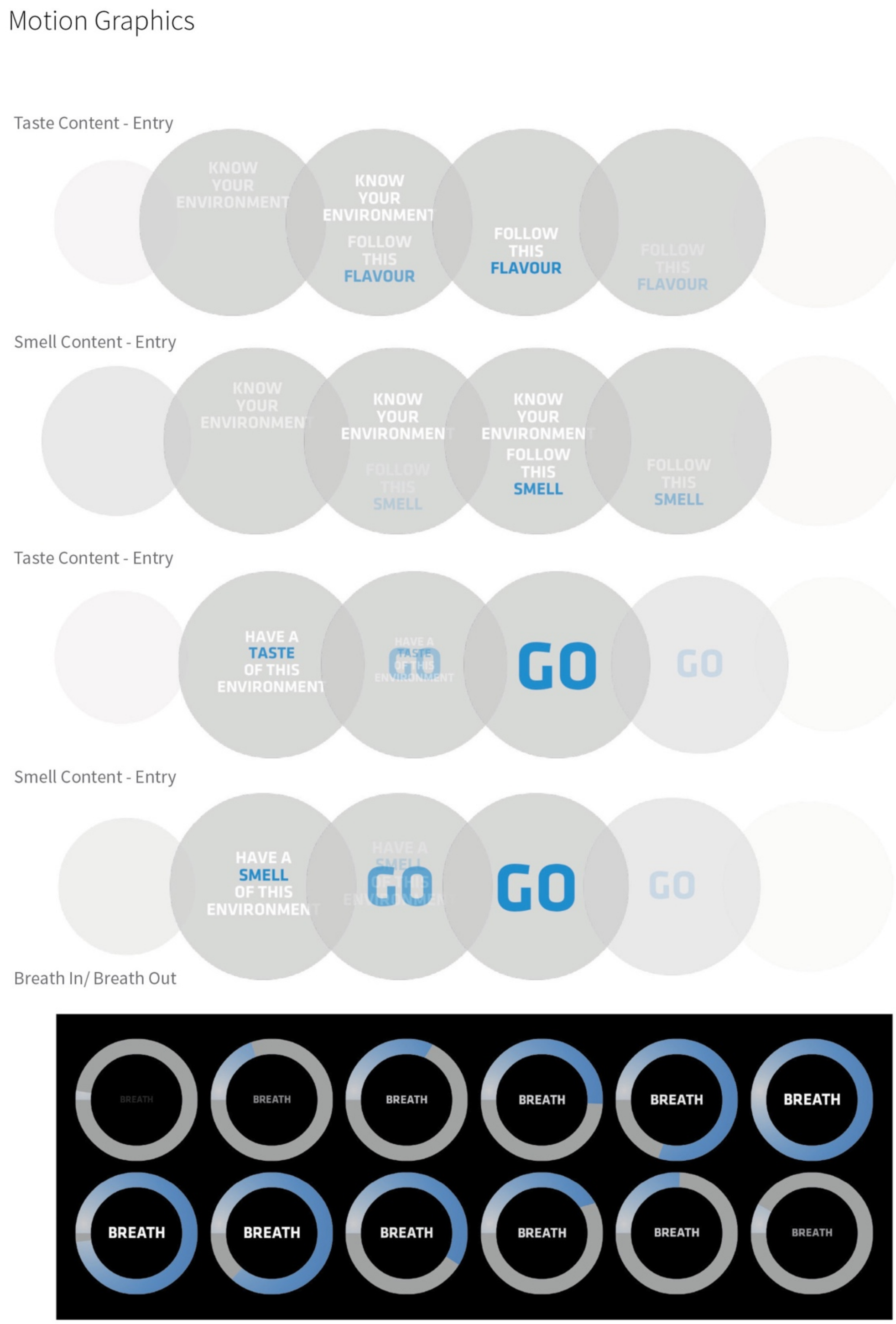


Figure 49 - Motion graphic design.

D 2.4. Production: Location image gallery

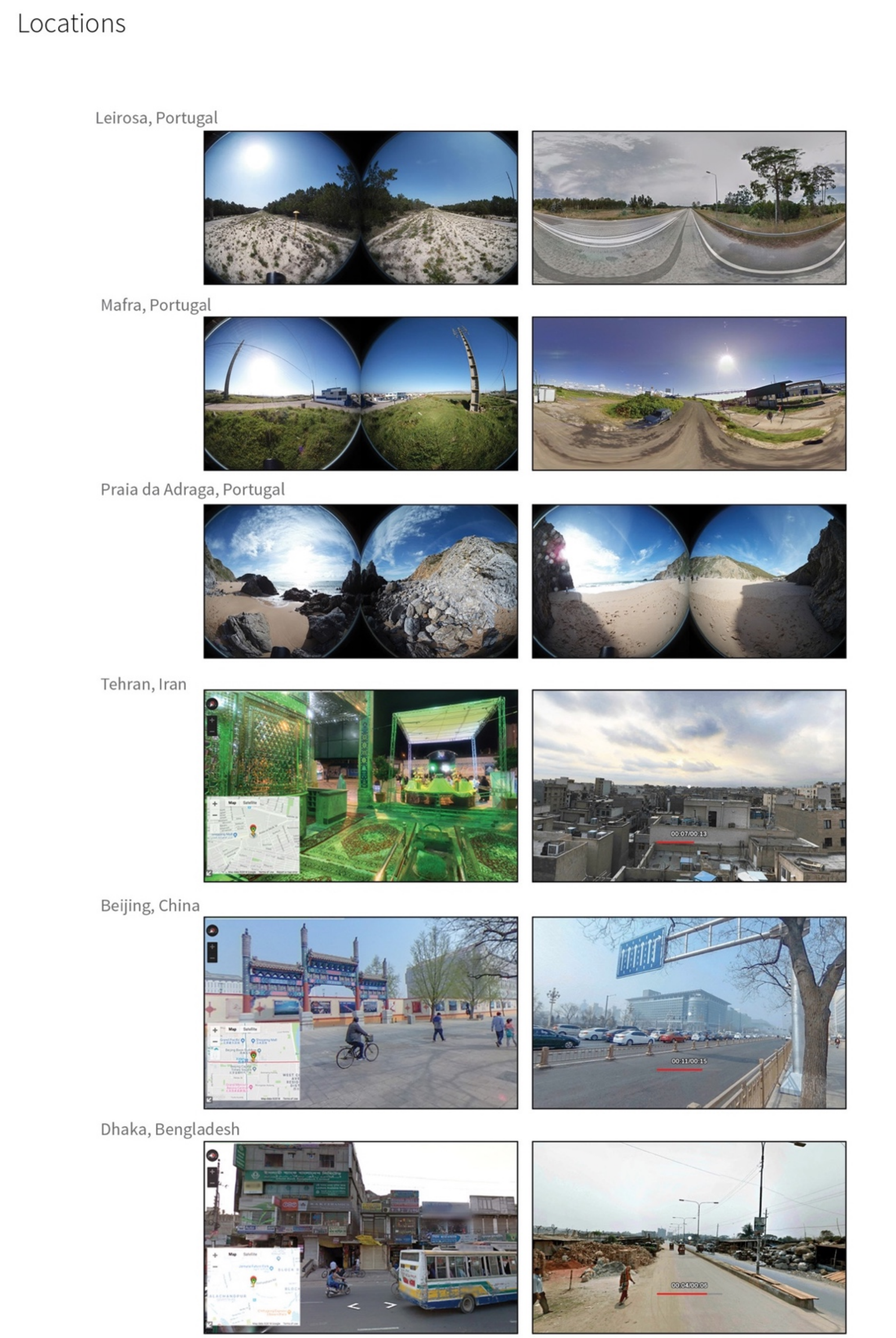


Figure 50 - Image collection sample.

D 2.5. Mobile application development

Implementation

Figure 51- Implementation aspects with Unity 3D.

D 3. Mobile Augmented Reality design project

D 3.1. Functional Specifications

Table 12 - MAR App Functional Specifications.

	Function	Description	Requisition	Inf. Arch.	Component
#1	Boot Screen	Content Loading		Home	Transversal
#2	New User	Main information about the user. Alternatively the user can sign up through Social Media Account.	Username: * Password: * Retype Password: First Name: * Last Name: * E-mail: * Confirm E-mail: * Terms & Privacy Policy acceptance: *	New User	Single line text fields
#2a	User	Basic main information data. Alternatively, the user can sign up through his Social Media Account.	E-mail: * Password: * Forgot Password?	Recorded User	Single line text fields
#3	User Profile	Profile info Summary.	1. Name 2. Username 3. Website 4. Email 5. Bio		
#4	Edit Profile settings	Changing Settings.	1. Profile photo 2. Name 3. Password 4. E-mail 5. Website 6. Bio		Single line text fields
#5	Home	Experience Option and access to user's previous experience records. Guide about how to use the app.	Menu: 1. Smell 2. Taste 3. My Account Guide: 4. Skip 5. Explore	Home	Buttons
#6	My Account	User's recorded experiences as also to his Profile. Option selection allows to access information history of Smell and Taste labelling, Actions suggestions as also profile settings.	Menu: 1. Smell 1a. Joined 1b. Placed 2. Taste 2a. Joined 2b. Placed 3. Actions 3a. My suggestions 4. My Profile		Selection Controls Two-line list

	SMELL FLOW				
#7	**Section Home**	Smell Section Home page displays georeferencing coordinates for user's spatial location. For Navigation, a bottom bar for main destinations that need to be accessible from anywhere in the Smell section App.	Bottom Navig. Bar Menu: 1. Home 2. Profile 3. Check it Out 4. Molecules	Label Marker visualization	
#8	**Geo referenced Label Marker View**	Tapping on Screen (Camera view) reveals recorded georeferenced Label Markers. When tapping on Marker, information about the label comes out. User can also Join or Place a new label for his spatial location.	1. Marker Information: 1a. Label name 1b. Author username 1c. Date and Time 1d. Pleasantness scale 1e. Emotion. 1f. Perceived intensity scale 2.Option Menu: 2a. Join 2b. Place	Label Interaction option	Buttons Modal Window
#9	**Molecules section.**	From Local Air Quality Index level information of main common pollution indicators. The most significant level is highlighted by a 3d model. More information is provided about its molecular structure and attributes. User can engage than with "Take Action" option to track pro-environmental behaviour suggestions.	Real Time Air Quality Index information provider. Menu: Take Action	Molecules	Chart Button
#10 #11	**Take Action**	Action List Menu to inspire Sustainable Behaviours. Tapping on List item leads to content development. User can also suggest an Action and share it with the *Earthsensum* community.		Take Action section	Button
#12 #12a	**Suggest and Share**	User suggest a pro-environmental Action within a limited character type field. On conclusion his suggestion is published within *Earthsensum* community and optional personal Social Media Account. A graphic chart does visualize how much user's previous suggestions have been "voted" by the community. A List Menu provides access to			Input text field. Modal Window. Button. Graphic Chart. Two-line list

		previous suggestions items.			
# 13	**Place**	Place option shows a modal window with User profile photo and username in relation with its spatial location.			Modal Window
#14 #14a #14b #14c #14d		Place button leads to the main Place Menu which allows the user to define and create a new smell label. Menu: 1. Shape 2. Source 3. Label 4. Joy	User Profile photo id. Menu: 1. Shape. 1a. Colour association: Colour wheel option. 1b. Texture symbolic associations: Angular, smooth and pointing texture options. 1c. Shape symbolic associations: Circle, triangle and star shape geom. options 2. Source identification: Smell Source List. 3. Semantic definition: 3a. Text in-put of user's description. 3b. Smell Categories List option. 4. Joy of odour perception: 4a. Pleasantness scale. 4b. Emotion description list. 4c. Perceived intensity scale.	Attributing new Smell Label to a geo marker.	Input text field. Button. Graphic Chart.
#15	**New Label Summary**	Users New Placed Label information summary.	"Check it Out" and "View All" option.	User Label Summary	Buttons
#16	**Check it Out**	"Check it Out" option allows to locate the new label on Map view.	Map view.	New Label location visualization.	GIS Modal Window
#17	**User Last Placed Smell**	Users Last Placed Label Information Summary.	Visualization of all parameters (#13 - #13d) and how many other users joined that placed smell. "Check it Out" option for geo visualization.	New Label information	Search feature Button
#18	**User Smell List**	Users Placed Label Information Summary.	List of user's placed smells.		Three-line list
#19	**Join**	Join option shows a modal window with User profile photo and username in		Joining a Smell Label.	Modal window

		relation with its spatial location.			
#20	**Join Label Menu**	Join Smell Label Menu allows the user to aggregate his qualitative description to previous spatial located smell label.	Menu: 1. Semantic description 2. Pleasantness scale. 3. Emotion description list. 4. Perceived intensity scale.		In-put filed text Slider buttons
#21	**Join Label Summary.**	Join Smell Label Summary.	Menu: 1. Space location 2. Semantic description 3. Date/ Time 4. Pleasantness scale. 5. Emotion description list. 6. Perceived intensity scale.		Modal Window
#22	**Joined Label List.**	Users Joined Label Item List.	List of user's joined smells.		Three-line list
	TASTE FLOW				
#23	**Taste Section Home**	Taste Section Home page displays georeferencing coordinates for user's spatial location. For Navigation, a bottom bar for main destinations that need to be accessible from anywhere in the taste section app.	Bottom Navigation Bar Menu: 1. Home 2. Profile 3. Check it Out 4. Molecules	Label Marker visualization	
#24	**Georeferenced Label Marker View**	Tapping on Screen (Map view) reveals recorded georeferenced Label Markers. When tapping on Marker, information about the label comes out. User can also Join or Place a new label for his spatial location.	1. Marker Information: 1a. Label name 1b. Author username 1c. Date and Time 1d. Pleasantness scale 1e. Emotion. 1f. Perceived intensity scale 2.Option Menu: 2a. Join 2b. Place	Label Interaction option	Buttons Modal Window
#25	**Molecules section.**	Air Quality Index of information of related Taste source location. The most significant level is highlighted by a 3d model. More information is provided about its molecular structure and attributes. User can engage than with "Take Action" option to track pro-environmental behaviour suggestions.	Real Time Air Quality Index information provider. Menu: Take Action	Molecules	Chart Button

#26 #27	**Take Action**	Action List Menu to inspire Sustainable Behaviours. Tapping on List item leads to content development. User can also suggest an Action and share it with the *Earthsensum* community.		Take Action section	Button
#28 #28a	**Suggest and Share**	User suggest a pro-environmental Action within a limited character type field. On conclusion his suggestion is published within *Earthsensum* community and optional personal Social Media Account. A graphic chart does visualize how much user's previous suggestions have been "voted" by the community. A List Menu provides access to previous suggestions items.			Input text field. Modal Window. Button. Graphic Chart. Two-line list
# 29	**Place**	Place option shows a modal window with User profile photo and username in relation with its spatial location.			
#30 #30a #30b #30c #30d	**Place Menu**	Place button leads to the main Place Menu which allows the user to define and create a new taste label. Menu: 1. Shape 2. Source 3. Label 4. Joy	User Profile photo id. Menu: 1. Shape. 1a. Colour association: Colour wheel option. 1b. Texture symbolic associations: Angular, smooth and pointing texture options. 1c. Shape symbolic associations: Circle, triangle and star shape geom. options 2. Source identification: Smell Source List. 3. Semantic definition: 3a. Text in-put of user's description. 3b. Smell Categories List option. 4. Joy of odour perception: 4a. Pleasantness scale. 4b. Emotion description list. 4c. Perceived intensity scale.	Attributing new Taste Label to a geo marker.	Input text field. Button. Graphic Chart.

#31	**New Placed Label Summary**	Users New Placed Label information summary.	"Check it Out" and "View All" option.	User Label Summary	Buttons
#32	**Check it Out**	"Check it Out" option allows to locate the new label on Map view.	Map view.	New Label location visualization.	GIS Modal Window
#33	**User Last Placed Label**	Users Last Placed Label information summary.	Visualization of all parameters (#30 - #30d) and how many other users joined that placed taste. "Check it Out" option for geo visualization.	New Label information	Search feature Button
#34	**User Placed Label item list**	Users Placed Label Information Summary.	List of user's placed smells.		Three-line list
#35	**Join**	Join option shows a modal window with User profile photo and username in relation with its spatial location.		Joining a Taste Label.	
#36	**Join Label Menu**	Join button leads to main Join Label Menu which allows the user to aggregate his qualitative description to previous spatial located taste label.	<u>Menu:</u> 1. Semantic description 2. Pleasantness scale. 3. Emotion description list. 4. Perceived intensity scale.	Joining a Taste Label.	In-put filed text Slider buttons
#37	**Join Label Summary.**	Joined Taste Label Summary.	Joined Taste Label information. 1. Space location 2. Semantic descript. 3. Date/ Time 4. Pleasantness scale. 5. Emotion description list. 6. Perceived intensity scale.		Modal Window
#38	**Joined Label List.**	Users Joined Label item list.	List of user's joined tastes.		Three-line list

D 3.2. Content development

Table 13 - MAR app content cevelopment.

	Section	Content
#2	New User	Welcome to our E*arthsensum* Community! Please enter your information to smell and taste your environment!
#3	User Profile	Welcome Back! Take a breath and taste your environment!
#04	Edit Profile	1. Change your profile photo. 2. Share what moves you:
#05	Home	Welcome! Click Explore to learn how to make sense with *Earthsensum!*
	SMELL	**Example: Carbon Monoxide**
#09	Section Molecules	"Smell your environment." Local smell environment Local Air quality index: - Carbon Monoxide (CO) - Ozone (O3) - Nitrogen Dioxide (NO2) - Sulphur Dioxide (So2) - Particulate Matter 2,5 (PM2.5) - Particulate Matter 10 (PM10) What's inside? Molecule Highlight: Carbon Monoxide Carbon monoxide (CO) is a colourless, odourless, and tasteless gas that is slightly less dense than air.
#09a	Molecules information	<Smell source> Carbon Monoxide
#10 #10a	Take Action	**ACTION 1** **Save energy** Look with attention at the labels on your appliances, and do not leave them on standby. Adjust the thermostat for heating and air conditioning. Using carefully home appliances, not only you can save energy as also money at the end of the month. **ACTION 2** **Less Fuel, more Cycling.** Whenever you can, use your car less, and instead, use sustainable transportation, such as bicycling, or use public transportation more often. For long-distance travel, consider trains. They are more sustainable than airplanes, which cause a great deal of the CO2 emitted into the atmosphere. In general, with car driving, every kilometre that you increase your speed, will considerably increase CO2 emissions and expenses. According to the CE, each litter of fuel equals 2.5 kilos of CO2 emitted into the atmosphere. **ACTION 3** **Demand Sustainable Measures** Your actions are important and have an impact on your life and your community. You can motivate your fellows! Demand measures toward a more sustainable life, any way that you can: promote renewable energy, regulatory measures such as

		properly labelling products (fishing method used, labels that specify product origins, transgenic information, among others), promote more sustainable public transportation, promote the use of bicycles and other non-polluting transportation methods in the city, correctly manage waste through recycling/reuse.
#12 #12a	Suggest and Share	1. Suggest and Share your Action. 2. My Suggestions timeline. 3. My Suggestions history.
#14 #14a #14b #14c #14d	Place	1.Shape: What shape does it have? 2.Source: Where does it come from? (Smell source list)* 3. Label: How to describe it? (Smell categories list)** 4a. Joy: How does it feel like? (Affective description list)*** 4b. What is the intensity? (Perceived intensity scale.) ***Smell Source List:** *Animals, Cleaning, Coffee, Complex, Construction, Emissions, Food/ Beverage, Humans, Industrial, Nature, Non-Food, Smoke, Subway, Synthetic Fragrance, Tobacco, Waste* ****Smell Categories List:** *Acid, Ammonia/Ruinous, Bakery, Burnt, Chemical, Cold, Decayed, Fish, Flower, Fruit, Garlic, Grass, Musky, Sour, Spices, Sweaty, Sweet, Warm,* Wood *****Smell Affective List:** *Agreeable, Aromatic, Bad, Characteristic, Delicate, Delicious, Delightful, Disgusting, Distinct, Empyreumatic, Evil, Exquisite, Faint, Fresh, Grateful, Heavy, Nasty, Nauseous, Offensive, Peculiar, Penetrating, Pleasant, Powerful, Pungent, Rich, Sickening, Strange, Strong, Suffocating,* Unpleasant
#15	New Label summary	1. Profile ID 2. Label 3. Date and Time 4. Source 5. Colour, shape and texture 6. Pleasantness scale 7. Perceived intensity scale.
#17	User Last Placed List	1. Profile ID 2. Last placed item ref. number 3. Last joined item ref. number 4. Search 5. Category 6. Geo coordinates 7. Label 8. Date and Time 9. Source 10. Colour, shape and texture 11. Pleasantness scale 12. Perceived intensity scale 13. Emotion description 14. Community vote
#18	List items	Each Item:

		1. Label 2. Geo coordinates 3. Date and Time
#20	Join Label	1. Profile ID 2. Label > Pleasantness (Joy) - How does it feel like? (Affective description list)*** - What is the intensity? (Scale Slider)
#21	Join Label Confirmation	"You joined". Info display: 1. Geo coordinates 2. Label 3. Date and Time 4. Pleasantness scale 5. Perceived intensity scale 6. Emotion description 7. View all
#22	Join Label Item List	Info display: for each Item: 1. Label 2. Geo coordinates 3. Date and Time
	TASTE	**Example: Spinach - Chlorophyll**
#09	Section Molecules	"Taste your environment." Your Taste Environment contains Chlorophyll. Vegetable like Spinach contains Chlorophyll. Its Molecular composition include Nitrogen atoms and Flavonoids. Carbon atoms are present in Flavonoids. Want to know more? Main global Spinach Top Exporter is China. Real Time Air Quality Index of Beijing. - Carbon Monoxide (CO) - Ozone (O3) - Nitrogen Dioxide (NO2) - Sulphur Dioxide (So2) - Particulate Matter 2,5 (PM2.5) - Particulate Matter 10 (PM10)
#09a	Molecules information	Taste source: Spinach - Chlorophyll. Vegetable like Spinach contains Chlorophyll. Its molecular composition include nitrogen atoms and flavonoids. Carbon atoms are present in Flavonoids Health benefits of Spinach includes anti-inflammatory effect and reducing risk of cancer, heart disease, asthma, and stroke. Nitrogen is the chief constituent of the Earth's atmosphere and a vital element in all known forms of life. Nitrogen is employed to make foamed rubber, plastics and to serve as a propellant gas for aerosol cans, and to pressurize liquid propellants for reaction jets. Carbon is the major component of coal used as fuels.
#10 #10a	Take Action	**ACTION2** **Eat low-carbon** - Reduce your meat consumption (livestock is one of the biggest contaminators of the atmosphere) and increase your consumption of fruits and vegetables. - Eat food that is local and in season: read the label and eat food that is produced in the area, avoid imports which create more emissions due to transportation. Also, eat seasonal items, to avoid less sustainable production methods. - Avoid excessive packaging and processed foods as much as possible

		ACTION 3 **Reduce, Reuse, Recycle** - Reduce: consume less, more efficiently. - Reuse: take advantage of second-hand markets, to give new life to items that you don't use anymore or find something that someone else has gotten rid of that you need. You'll be saving money and reducing your consumption. Bartering is also a practical solution. - Recycle: packaging, waste from electronics, etc. Did you know that you can save over 730 kilos of CO2 each year just by recycling half of the garbage produced at home? **ACTION 4** **Choose Fair Trade Products** Fairtrade is an alternative approach to conventional trade and is based on a partnership between producers and consumers. When farmers can sell on Fairtrade terms, it provides them with a better deal and improved terms of trade. This allows them the opportunity to improve their lives and plan for their future. Fairtrade offers consumers a powerful way to reduce poverty through their everyday shopping. Fairtrade rewards and encourages farming and production practices that are environmentally sustainable. Producers are also encouraged to strive toward organic certification. Producers must: - Protect the environment in which they work and live. This includes areas of natural water, virgin forest and other important land areas and dealing with problems of erosion and waste management. - Develop, implement and monitor an operations plan on their farming and techniques. This needs to reflect a balance between protecting the environment and good business results. - Follow national and international standards for the handling of chemicals. There is a list of chemicals which they must not use. - Not, intentionally, use products which include genetically modified organisms (GMO). - Work out and monitor what affect their activities are having on the environment. Then they must plan on how they can lessen the impacts and keep checking that this plan is carried out. > Find a Fair-Trade store near you.
#28 #28a	Suggest and Share	1. Suggest and Share your Action. 2. My Suggestions timeline. 3. My Suggestions history.
#30	Place	1.Shape: What shape does it have? 2.Source: Where does it come from? (Taste Source list)* 3. Label: How to describe it? (Taste Categories list)** 4a. Joy: How does it feel like? (Affective description list)*** 4b. What is the intensity? (Perceived intensity scale.)

		***Taste Source List:** *Dairy Products* *Fruits* *Leaves* *Legume* *Meat* *Poultry* *Root* *Seafood* *Seeds* *Spice* *Whole Grain*	****Taste Categories List:** *Bitter* *Bland* *Crunchy* *Dry* *Greasy* *Moist* *Piping hot* *Rich* *Salty* *Savoury* *Scrumptious* *Sour* *Spicy* *Sugary* *Sweet* *Tasty*	*****Taste Affective List:** *Amazing* *Appealing* *Appetizing* *Delectable* *Delicious* *Delightful* *Disgusting* *Divine* *Enjoyable* *Enticing* *Excellent* *Exquisite* *Extraordinary* *Fantastic* *Finger* *Heavenly* *Licking* *Lip Smacking* *Luscious* *Marvellous* *Mouth-watering* *Palatable* *Pleasant* *Pleasing* *Satisfying* *Scrumptious* *Strange* *Superb* *Tantalizing* *Tasty* *Terrific* *Unpleasant* *Wonderful* *Yummy*
#31	**New Label summary**	1. Profile ID 2. Label 3. Date and Time 4. Source	5. Colour, shape and texture 6. Pleasantness scale 7. Perceived intensity scale.	
#33	**User Last Placed List**	1. Profile ID 2. Last placed item ref. number 3. Last joined item ref. number 4. Search 5. Category 6. Geo coordinates 7. Label	8. Date and Time 9. Source 10. Colour, shape and texture 11. Pleasantness scale 12. Perceived intensity scale 13. Emotion description 14. Community vote	
#34	**List items**	Each Item: 1. Label 2. Geo coordinates 3. Date and Time		
#36	**Join Label**	1. Profile ID 2. Label 3. Pleasantness (Joy) - How does it feel like? (Affective description List) *** - What is the intensity? (Scale Slider)		
#37	**Join Label Confirmation**			

#38	**Join Label Item List**	Each Item: 1. Label 2. Geo coordinates 3. Date and Time

Content information sources:

Several online sources provided information to compile the contents featured in the wireframes. These addressed smell and taste descriptors [258], [304], [305]; as also pro-environmental actions by energy savings [306][307]; Fairtrade [308] and carbon footprint calculators [309]–[312]. Information about flavonoids [313], nitrogen [314], spinach[315] and chlorophyll [316] contributed to the molecule information section, among others.

D 3.3. Organizing and structuring: Information Architecture

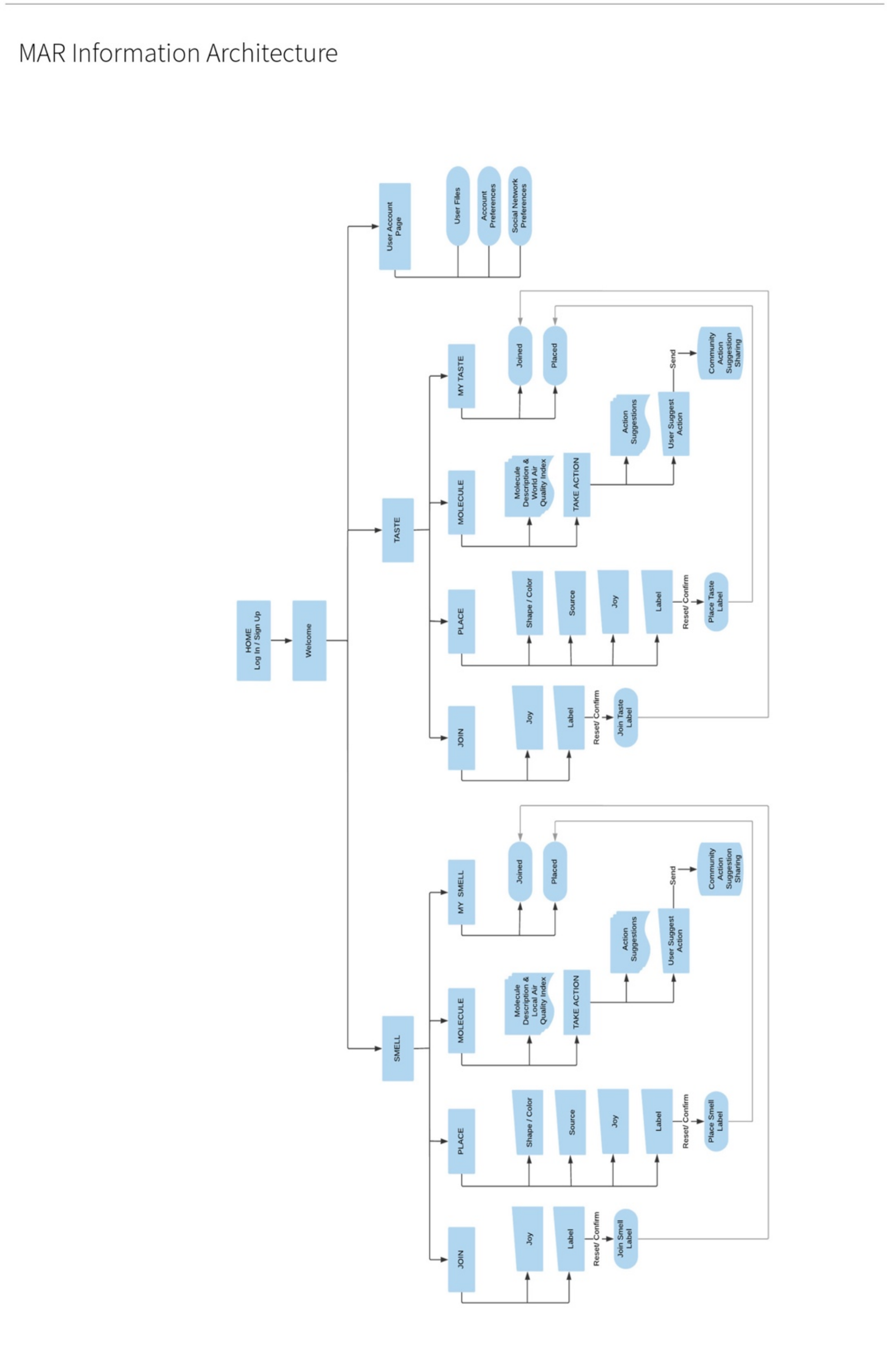


Figure 52 - MAR Information Architecture.

D 3.4. Prototyping: Wireframe mock up

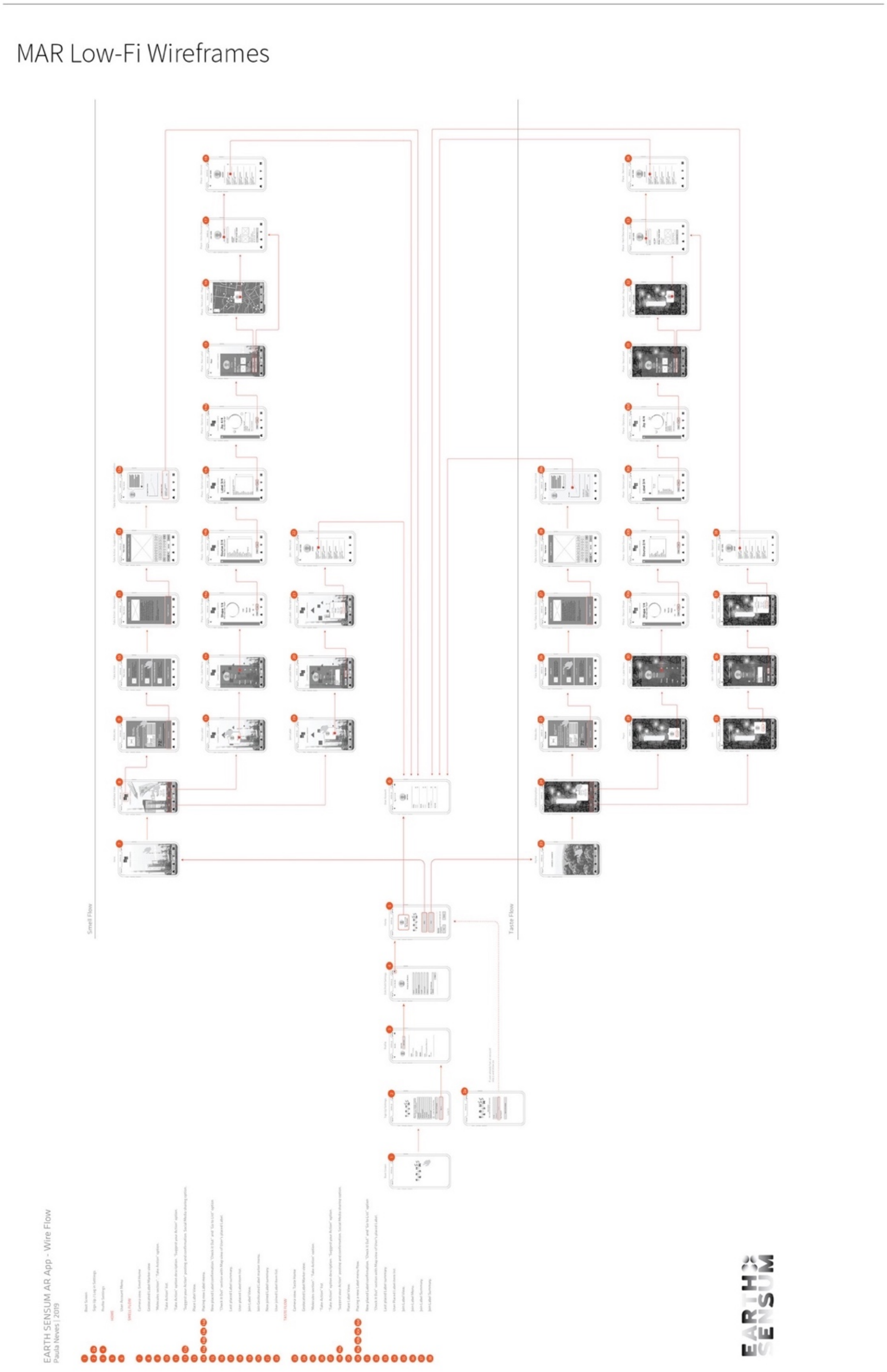


Figure 53 – MAR Low-Fi Wireframe diagram.

D 3.5. Visual Design framework: Consistency and identity

Visual Design Concept

Figure 54 – MAR Visual Design Concept.

D 3.6. Prototyping: High- Fi wireframe mock up

High-Fi Wireframes

Figure 55 - MAR High-Fi Wireframe flow.

Appendix F

Complementary UX Evaluation Data

F.1. User Interface concept

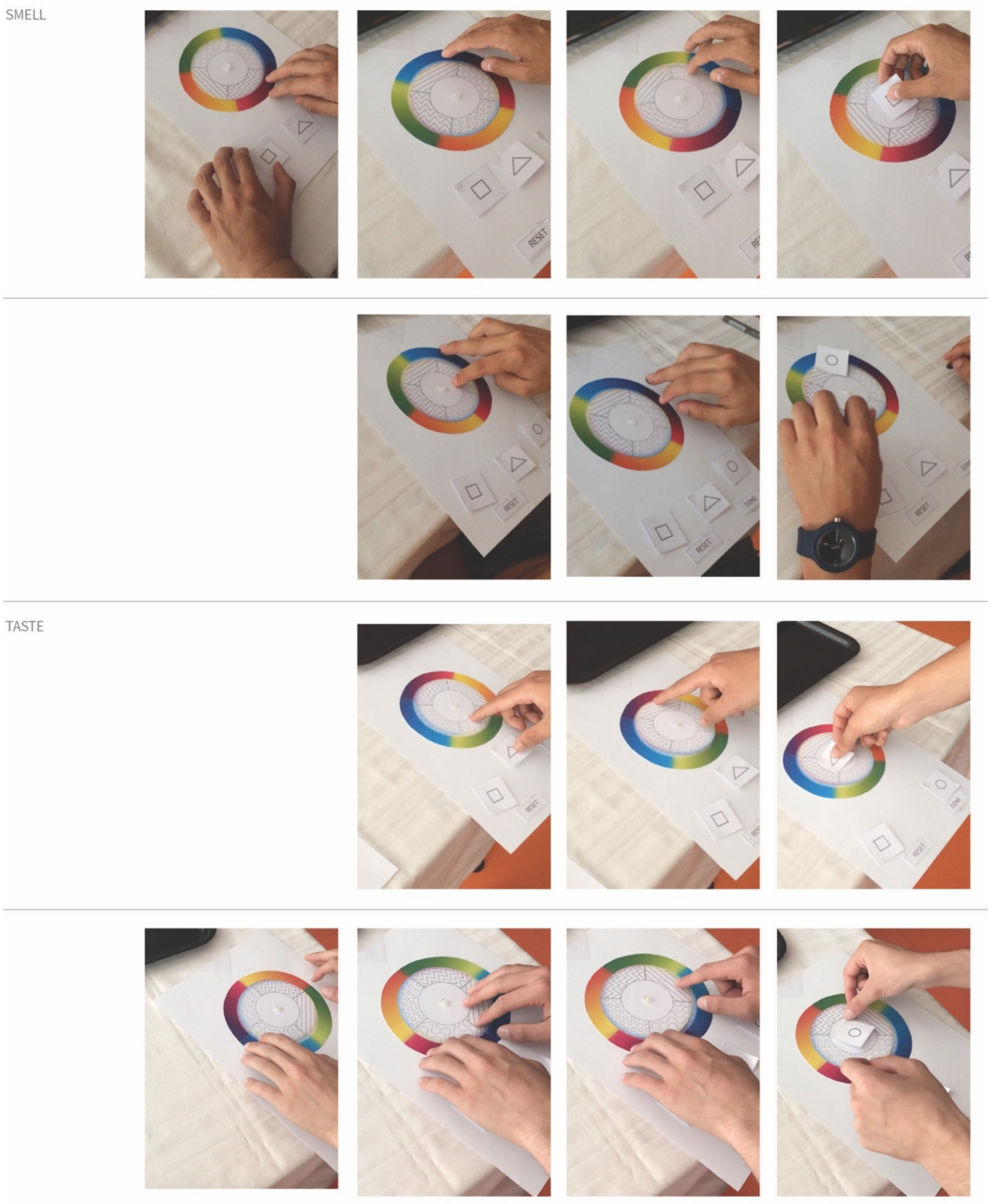


Figure 56 - MAR Interface Paper Prototype.

F.2. User Experience evaluation summary – quantitative data

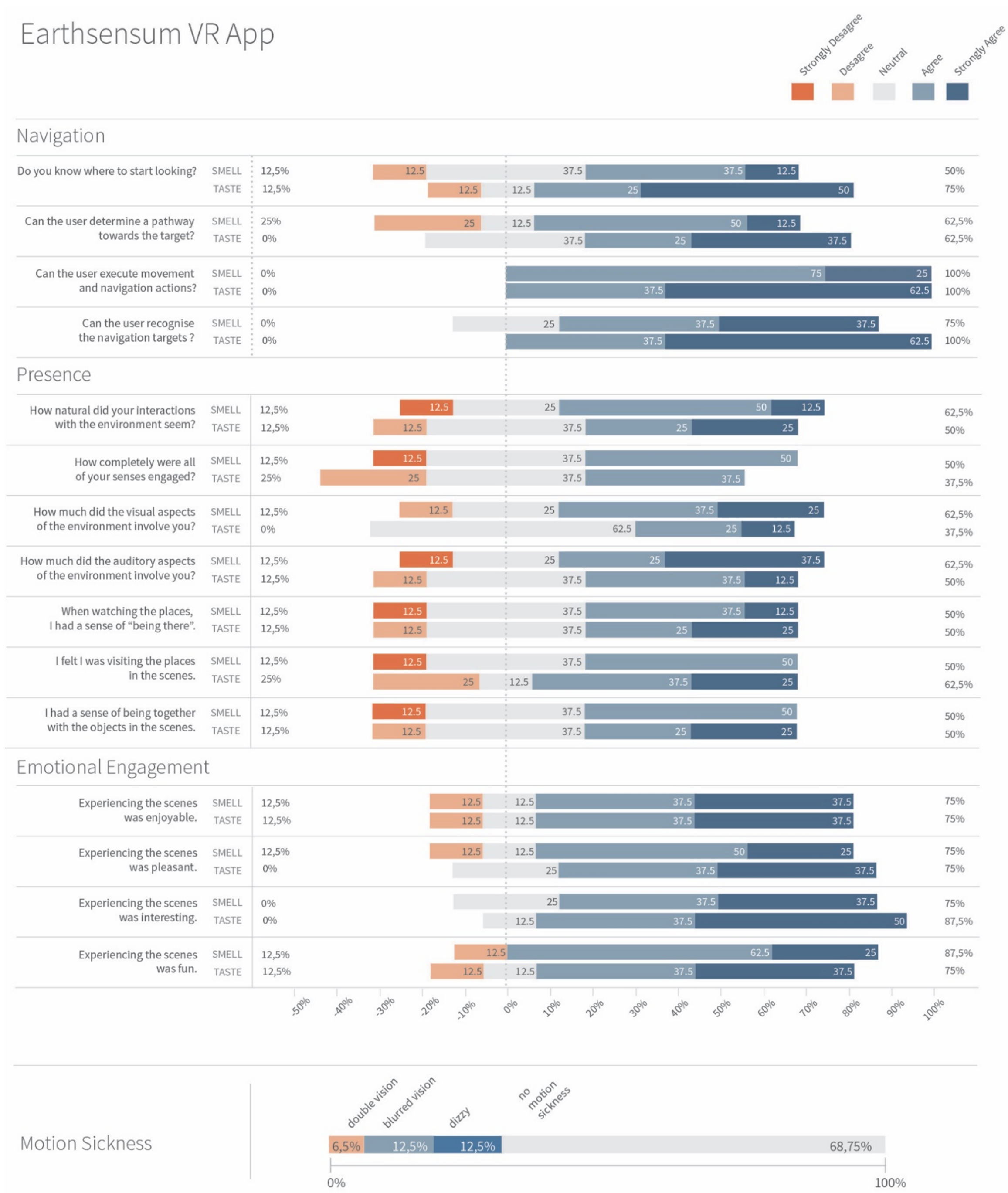


Figure 57 - MVR UX evaluation for navigation, presence and emotional engagement of total 8 participants (100%) in each experiment group (smell and taste).
Motion sickness evaluation corresponds to total 16 participants (100%) responses.

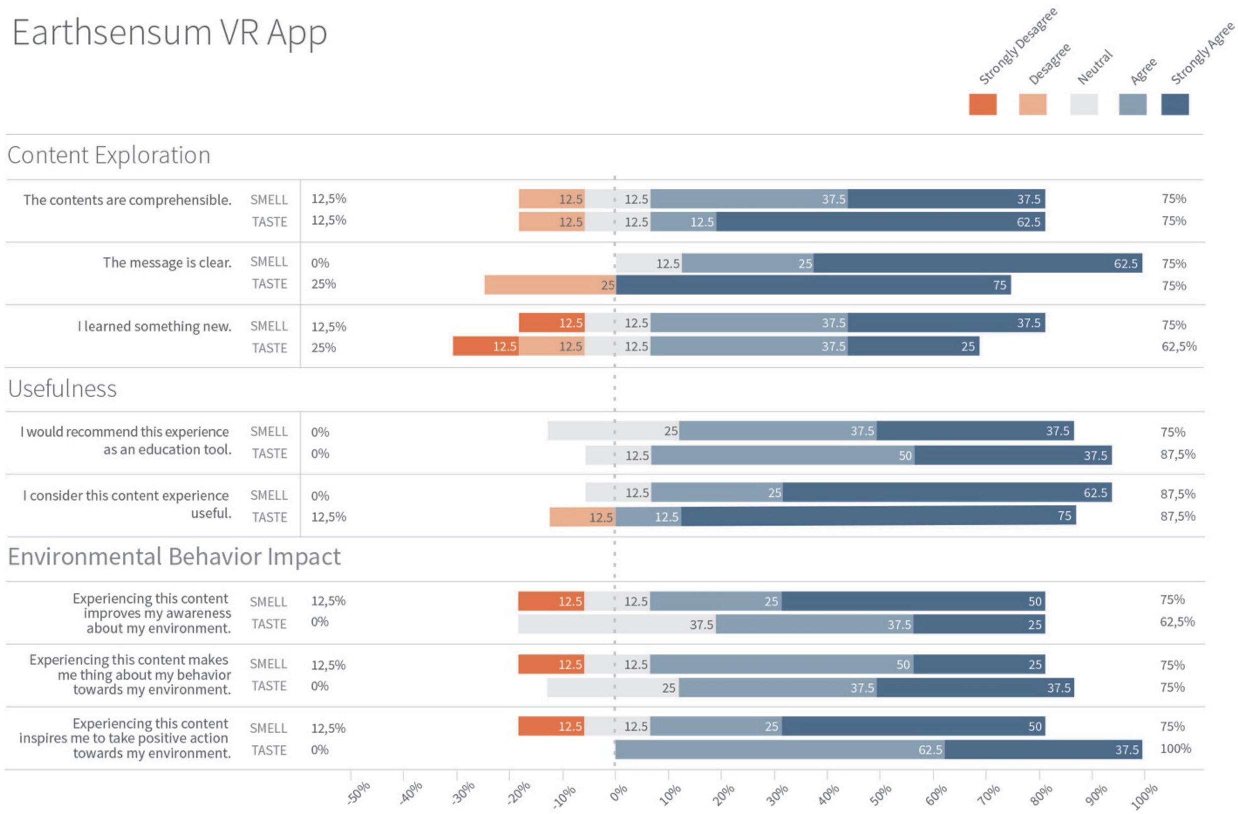


Figure 58 - MVR UX evaluation for content exploration, usefulness and environmental behaviour impact of total 8 participants (100%) in each experiment group (smell and taste).

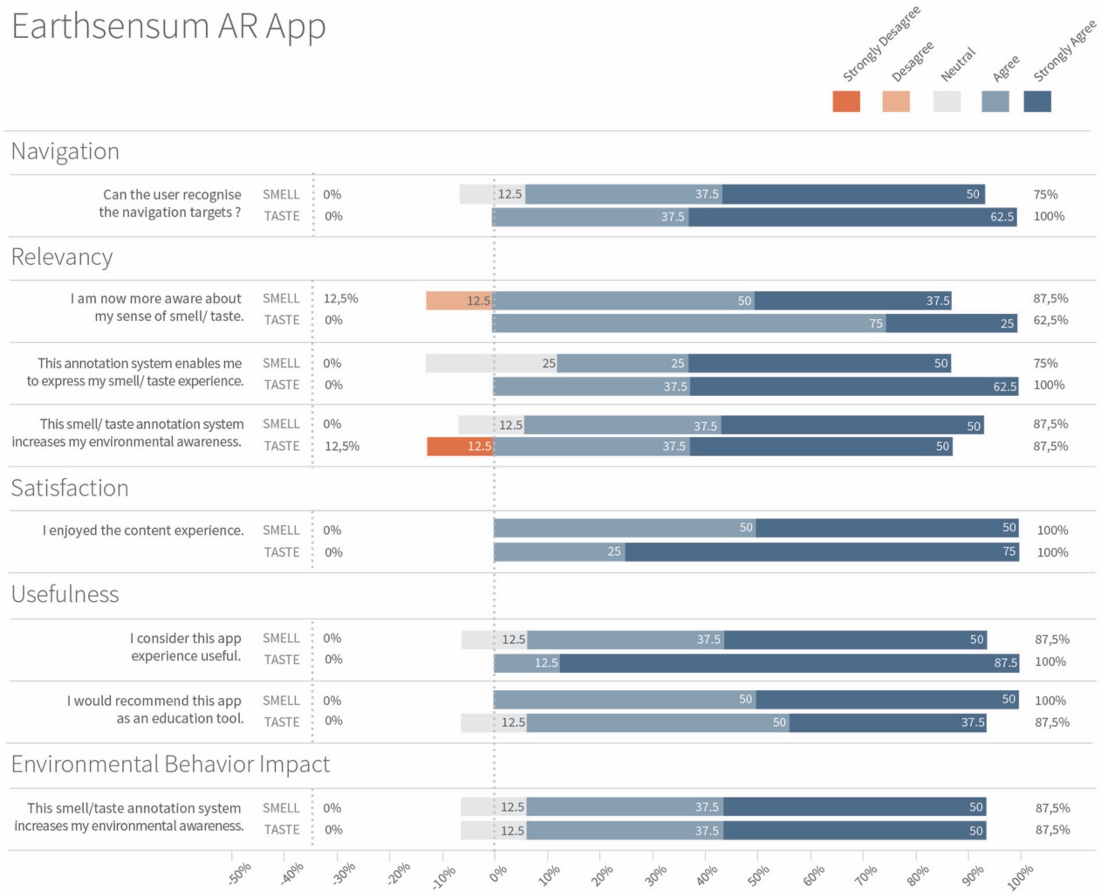


Figure 59 –MAR UX Evaluation for navigation, relevancy, satisfaction, usefulness and emotional engagement of total 8 participants (100%) in each group (smell and taste).